Cost Report for Alternatives
Presented in the

Draft Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility

August 2000

PREFACE

In the *Draft Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility*, the U.S. Department of Energy (DOE) proposes to enhance its existing nuclear facility infrastructure to accommodate new and expanded missions in the areas of nuclear research and development and isotope production. The draft programmatic environmental impact statement evaluates alternatives that could be implemented to accomplish these missions. This Cost Report presents the costs associated with implementing each of these alternatives.

A major purpose of this Cost Report, as noted in the Summary, is to assist DOE in its recognition of the financial implications of its programmatic decisions and to inform the public about these costs.

To best serve this purpose, the costs of each alternative were evaluated in familiar terms: facility investments and operating costs. A specialized knowledge of the technologies underlying these alternatives is not necessary to understand this Cost Report.

Most of the alternatives for expanding DOE's current nuclear infrastructure involve the extensive modification of existing facilities and equipment, the construction of new facilities, or the restart of existing facilities (i.e., the Fast Flux Test Facility at Hanford). Cost estimates for some of these alternatives were based on preconceptual design and, as such, reflect uncertainties and contingencies. It is therefore important to bear in mind these limitations in the accuracy of these cost estimates when making comparative judgments between alternatives.

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ACRONYMS AND ABBREVIATIONS

ANS	Advanced Neutron Source
ATR	Advanced Test Reactor
CDR	Conceptual Design Report
CLWR	commercial light water reactor
CPP–651	Chemical Processing Plant Building 651
DOE	U.S. Department of Energy
EIS	environmental impact statement
ENR	*Engineering News Record*
FDPF	Fluorinel Dissolution Process Facility
FFTF	Fast Flux Test Facility
FMEF	Fuels and Materials Examination Facility
FY	fiscal year
Hanford	Hanford Site
HEU	highly enriched uranium
HFIR	High Flux Isotope Reactor
INEEL	Idaho National Engineering and Environmental Laboratory
LANL	Los Alamos National Laboratory
LEDA	low-energy demonstration accelerator
MOX	mixed oxide
MUSC	Medical University of South Carolina
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NERAC	Nuclear Energy Research Advisory Committee
NI PEIS	Nuclear Infrastructure Programmatic Environmental Impact Statement
ORNL	Oak Ridge National Laboratory
PEIS	programmatic environmental impact statement
PNNL	Pacific Northwest National Laboratory
REDC	Radiochemical Engineering Development Center
RPL/306-E	Radiochemical Processing Laboratory and Hanford 300 Area Building 306-E
SGT	safeguards transporter
SRS	Savannah River Site
SST	safe secure trailer
TRIGA	Training Research and Isotope Production Reactor
WBS	work breakdown structure

SUMMARY

S.1 INTRODUCTION AND BACKGROUND

The following is a summary of a report evaluating the costs associated with the U.S. Department of Energy (DOE) proposal to enhance its existing nuclear facility infrastructure to accommodate new and expanding missions in the areas of nuclear research and development and isotope production. DOE currently does not have sufficient steady-state irradiation sources to meet the Nation's projected needs for: (1) isotopes for medical and industrial uses, (2) fuel to power future U.S. National Aeronautics and Space Administration (NASA) spacecraft, and (3) nuclear research and development.

The alternatives for the proposed expanded isotope production missions that were evaluated in this Cost Report are presented in the *Draft Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility* (Nuclear Infrastructure Programmatic Environmental Impact Statement [NI PEIS]) (DOE 2000).

Costs of potential decisions are not typically evaluated in an environmental impact statement (EIS), but DOE recognizes that the financial implications of its future programs are important considerations for decision making and has resolved to inform the public about those costs. The findings of this Cost Report and public input received on the NI PEIS are among the factors that DOE will consider when preparing the Record of Decision.

The programmatic alternatives considered in this Cost Report focus on the use of irradiation facilities that are currently operating, could be brought online, or could be constructed and operated to meet DOE's irradiation needs. Thus, the report considers the following alternatives (presented in more detail in Chapter 2 of the NI PEIS):

- **No Action Alternative**, maintaining the status quo; that is, DOE's existing facilities would continue to meet their current mission requirements within their operating levels, and DOE would not enhance existing U.S. nuclear facility infrastructure or expand its current missions to accommodate new missions.

- **Alternative 1**, which includes resuming operation of the Fast Flux Test Facility (FFTF) at the Hanford Site (Hanford) in Richland, Washington

- **Alternative 2**, using only existing operational facilities (the Advanced Test Reactor [ATR] at Idaho National Engineering and Environmental Laboratory [INEEL], the High Flux Isotope Reactor [HFIR] at Oak Ridge National Laboratory [ORNL], or a generic commercial light water reactor [CLWR]) to accommodate the plutonium-238 production mission

- **Alternative 3**, constructing and operating one or two new accelerator(s) at an existing DOE site

- **Alternative 4**, constructing and operating a new research reactor at an existing DOE site

- **Alternative 5**, permanently deactivate Hanford's FFTF without enhancing U.S. nuclear facility infrastructure to accommodate new or expanded missions. Although Alternatives 2, 3, and 4 include the deactivation of FFTF, Alternative 5 is included as a stand-alone alternative in response to numerous public comments received during the scoping period for the NI PEIS.

The No Action Alternative and Alternatives 1 through 4 each have several options, evaluated in this Cost Report. These options involve primarily DOE facilities that could be used for fabrication, storage, and postirradiation processing of the targets necessary for the program missions. Among the facilities proposed are: (1) the Radiochemical Engineering Development Center (REDC) at ORNL, (2) the Fluorinel Dissolution Process Facility (FDPF) and/or the Chemical Processing Plant (CPP) Building 651 (CPP–651) (storage only) at INEEL, (3) the Fuels and Materials Examination Facility (FMEF) at Hanford, (4) Building 325, the Radiochemical Processing Laboratory (RPL), and Building 306–E at Hanford, and (5) a new facility to be constructed and operated at an existing DOE site to support the one or two new accelerator or new research reactor alternatives. **Table S-1** presents an overview of the alternatives and options evaluated in the NI PEIS.

S.2 DECISIONS TO BE MADE

In reaching programmatic decisions regarding potential expansion of its existing nuclear facility infrastructure, DOE will factor the analytical environmental results of the NI PEIS together with the findings presented in this Cost Report and the NI Nonproliferation Impacts Assessment[1], the *Nuclear Science and Technology Infrastructure Roadmap,* recommendations of the Nuclear Energy Research Advisory Committee (NERAC) and its various subcommittees, public input, and other DOE policy and programmatic considerations.

With the benefit of this broad base of information, DOE intends to make the following decisions:

- Whether to expand its current nuclear facility infrastructure to meet projected requirements for future medical and industrial isotope production, plutonium-238 production, and nuclear research and development.

- If a decision is made to expand DOE's existing nuclear facility infrastructure, whether to (1) construct new facilities (one or two accelerators or a research reactor), or (2) restart FFTF at Hanford as part of a nuclear infrastructure expansion program and, if not, whether to remove FFTF from standby mode and permanently deactivate it in preparation for its eventual decontamination and decommissioning.

- If a decision is made not to expand DOE's existing nuclear facility infrastructure, decide whether to (1) select from existing operating facilities those needed to support the proposed plutonium-238 mission, or (2) continue purchasing plutonium-238 from Russia to support future NASA space missions, and (3) whether DOE inventories of neptunium-237 should be relocated and stored for future plutonium-238 production needs. Existing operating facilities performing medical, research, and/or industrial isotope production and/or nuclear research and development missions would continue to support existing missions at current levels.

The programmatic decisions to be made in association with the NI PEIS are the responsibility of the DOE Office of Nuclear Energy, Science and Technology. In addition to the range of reasonable programmatic alternatives evaluated in the NI PEIS, DOE could choose to combine components of several alternatives in selecting the most appropriate strategy. For example, DOE could select a low-energy accelerator to produce medical, research, and industrial isotopes, and an existing operating reactor to produce plutonium-238 and conduct nuclear research and development. If alternatives were selected involving the siting, construction, and operation of one or two new accelerators or a new research reactor, appropriate site- and project-specific National Environmental Policy Act (NEPA) documentation, tiered from the NI PEIS, would be prepared.

[1]The DOE Office of Arms Control and Nonproliferation is analyzing the nonproliferation policy impacts of FFTF's restart, and of the other alternatives and their various options, and will be reporting its findings in the *Nonproliferation Impacts Assessment for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility* (Nuclear Infrastructure Nonproliferation Impacts Assessment).

Table S–1 Alternatives and Options Evaluated in the NI PEIS

			Plutonium-238 Production Mission		*Medical and Industrial Isotopes Production and Nuclear Research and Development Mission*	
	Option Number	***Irradiation Facility***	***Storage Facility***	***Target Fabrication and Processing Facility***	***Storage Facility***	***Target Fabrication and Processing Facility***
No Action Alternative	1	–	–	–	–	–
	2	–	REDC	–	–	–
	3	–	CPP–651	–	–	–
	4	–	FMEF	–	–	–
Alternative 1: Restart FFTF	1	FFTF [a]	REDC	REDC	RPL/306–E	RPL/306–E
	2	FFTF [a]	FDPF/CPP–651	FDPF	RPL/306–E	RPL/306–E
	3	FFTF [a]	FMEF	FMEF	FMEF	FMEF
	4	FFTF [b]	REDC	REDC	RPL/306–E	RPL/306–E
	5	FFTF [b]	FDPF/CPP–651	FDPF	RPL/306–E	RPL/306–E
	6	FFTF [b]	FMEF	FMEF	FMEF	FMEF
Alternative 2: Use Only Existing Operational Facilities	1	ATR	REDC	REDC	–	–
	2	ATR	FDPF/CPP–651	FDPF	–	–
	3	ATR	FMEF	FMEF	–	–
	4	CLWR	REDC	REDC	–	–
	5	CLWR	FDPF/CPP–651	FDPF	–	–
	6	CLWR	FMEF	FMEF	–	–
	7	HFIR and ATR	REDC	REDC	–	–
	8	HFIR and ATR	FDPF/CPP–651	FDPF	–	–
	9	HFIR and ATR	FMEF	FMEF	–	–
Alternative 3: Construct New Accelerator(s)	1	New	REDC	REDC	New [c]	New [c]
	2	New	FDPF/CPP–651	FDPF	New [c]	New [c]
	3	New	FMEF	FMEF	New [c]	New [c]
Alternative 4: Construct New Research Reactor	1	New	REDC	REDC	New [c]	New [c]
	2	New	FDPF/CPP–651	FDPF	New [c]	New [c]
	3	New	FMEF	FMEF	New [c]	New [c]
Alternative 5: Permanently Deactivate FFTF (with no new missions)	–	–	–	–	–	–

Key: RPL/306-E = Radiochemical processing Laboratory and Hanford 300 Area Building 306-E.

a. Hanford FFTF would start up and operate with onsite and German mixed oxide (MOX) fuel and then highly enriched uranium (HEU) fuel.

b. Hanford FFTF would start up and operate with only the onsite MOX fuel and then HEU fuel.

c. The new facility would not be required if a DOE site with available support capability and infrastructure is selected.

The programmatic decisions to be reached in association with the NI PEIS are schematically presented in **Figure S–1.** In accordance with the first-tier "yes or no" decision to be made (as seen in Figure S–1), alternatives analyzed in the NI PEIS were arranged into two groups—nonexpanded infrastructure alternatives, including the No Action Alternative and Alternatives 2 and 5; and expanded infrastructure alternatives, including Alternatives 1, 3, and 4. Cost estimates for the nonexpanded and expanded infrastructure alternatives were also arranged into these groups and are presented in Section S.3, Results and Conclusions.

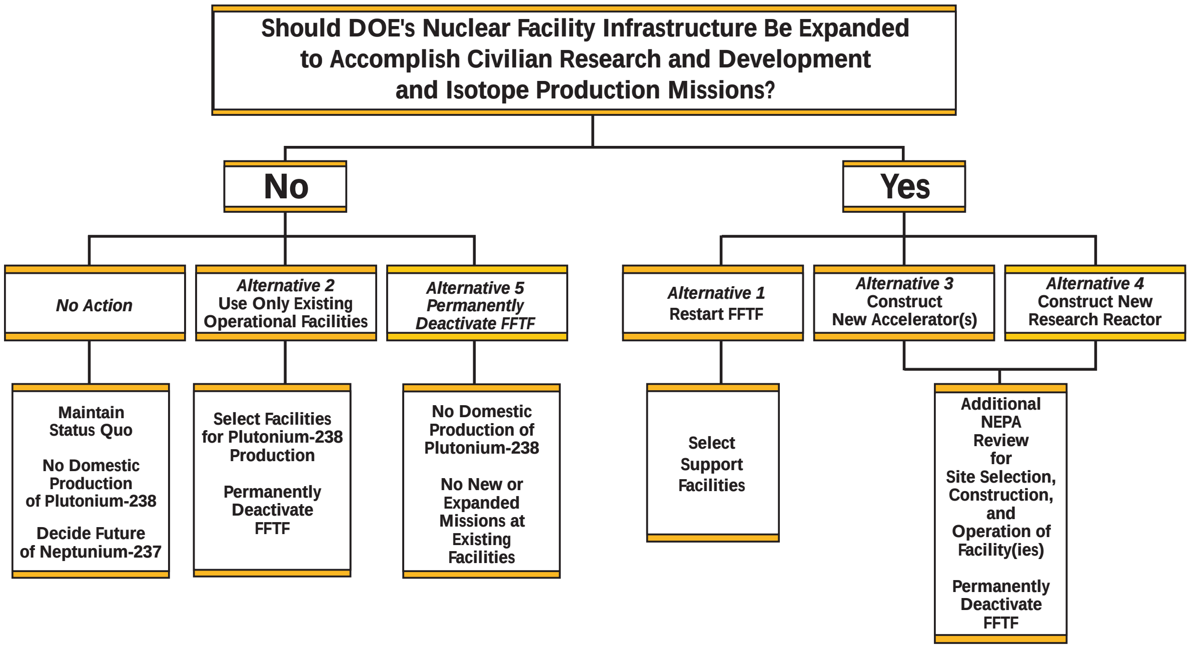

Figure S–1 Pending Decisions

S.3 Results and Conclusions

Summaries of cost estimates for the nonexpanded and expanded infrastructure alternatives identified in Figure S–1 are presented in **Tables S–2** and **S–3**. All figures shown represent millions of FY 2000 dollars. No credit was taken for projected revenues from medical and industrial isotope sales, or from fees paid by domestic or international users of facilities.

Nonexpanded Infrastructure Alternatives

A summary of the estimated costs of the nonexpanded infrastructure alternatives (the No Action Alternative and Alternatives 2 and 5 of the NI PEIS) is presented in Table S–2. Capital costs (costs of modifying existing facilities), costs for permanently deactivating FFTF (where appropriate), annual operating costs, and transportation costs are presented for irradiation facilities and neptunium-237 storage and plutonium-238 processing facilities. In addition, costs for the purchase and transport of Russian plutonium-238 are presented. DOE would continue its medical and industrial isotope production and nuclear research and development activities of the current operating levels of existing facilities.

Table S–2 Summary of Estimated Costs of Nonexpanded Infrastructure Alternatives (Millions of FY 2000 Dollars)

Cost Elements	*No Action*				*Alternatives*									
					Alternative 2: Use Only Existing Operational Facilities									*Alternative 5: Deactivate FFTF*
					ATR			*CLWR*			*ATR and HFIR*			
Irradiation Facilities														
FFTF in standby mode (annual) (A)	40.8													
FFTF deactivation (B)					281.2			281.2			281.2			281.2
Startup; target development, testing, and evaluation (C)					2			20			3.5			
Operations (annual) (D)					8.1			5.1			8.1			
Russian Plutonium-238														
Purchase 5 kilograms (11 pounds) of Russian Plutonium-238 (annual)	8.7 [a]													
Transport Russian Plutonium-238 to LANL (annual) (E)	0.14													
Total Annual Costs	**8.84**													
Processing Facility Alternative Options	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Neptunium-237 Storage and Plutonium-238 Processing Facilities		**REDC**	**CPP-651**	**FMEF**	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**	
Modification and startup costs (F)		16.9	2.12	19.3	51.2	37.2	72.8	55.1	41.2	72.8	51.2	37.2	72.8	
Operations (annual) (G)		1.5	1.5	2.6	7.8	6.7	15.3	10.8	9.7	18.3	7.8	6.7	15.3	
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities [b]														
Modification or construction and startup costs														
Operations (annual)														
Combined Estimated Costs														
Total Costs (B+C+F)	**0**	16.9	2.12	19.3	334.4	320.4	356	356.3	342.4	374	335.9	321.9	357.5	281.2
Annual Costs (A+D+E+G)	49.6	51.1	51.1	52.2	15.9	14.8	23.4	15.9	14.8	23.4	15.9	14.8	23.4	0
Plutonium-238 Production Transportation														
Neptunium-237 from SRS (total)		1.4	7.1	8.5	1.4	7.1	8.5	1.4	7.1	8.5	1.4	7.1	8.5	
Total annual plutonium-238 production shipping and handling costs					0.39	0.24	0.32	0.41	0.40	0.46	0.34	0.29	0.35	
Medical and Industrial Isotope Transportation (annual) [b]														

Key: LANL = Los Alamos National Laboratory; SRS = Savannah River Site.

a. Based on FY 2000 contract year eight, \$1.74 million per kilogram × 5 kilograms. Succeeding year purchase price escalated at a contractual 3.5 percent per year for the remaining two years of the contract.

b. DOE would continue its medical and industrial isotope production and nuclear research and development activities at the current operating levels of existing facilities.

Note: Shaded areas indicate that no costs would be incurred under that alternative and/or option.

Table S–3 Summary of Estimated Costs of Expanded Infrastructure Alternatives (Millions of FY 2000 Dollars)

Cost Elements	*Alternatives*								
	Alternative 1: Restart FFTF			*Alternative 3: Construct New Accelerator(s)*			*Alternative 4: Construct New Research Reactor*		
Irradiation Facilities									
Modification or construction and startup, including target development, testing, and evaluation	314			1,096.0			312		
FFTF deactivation				281.2			281.2		
Total costs (A)	**314**			**1,377.2**			**593.2**		
Operations (annual) [a] (B)	58.9			45.1			25		
Processing Facility Alternative Options	**1 and 4 [b]**	**2 and 5 [b]**	**3 and 6 [b]**	**1**	**2**	**3**	**1**	**2**	**3**
Plutonium-238 Production Facilities	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**
Modification and startup costs (C)	55.1	41.2	72.8	51.2	37.2	72.8	51.2	37.2	72.8
Operations (annual) (D)	10.8	9.7	18.3	7.8	6.7	15.3	7.8	6.7	15.3
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities	**RPL/306-E**		**FMEF**	**New Processing Support Facility**			**New Processing Support Facility**		
Modification or construction and startup costs (E)	29.4		36.8	71.1			71.1		
Operations (annual) (F)	12.1		12.9	23.3			23.3		
Combined Estimated Costs									
Total Costs (A+C+E)	398.5	384.6	423.6	1,499.5	1,485.5	1,521.1	715.5	701.5	737.1
Annual Operating Costs [c] (B+D+F)	81.8	80.7	90.1	76.2	75.1	83.7	56.1	55	63.6
Plutonium-238 Production Transportation									
Neptunium-237 from SRS (total)	1.4	7.1	8.5	1.4	7.1	8.5	1.4	7.1	8.5
Total annual plutonium-238 production shipping and handling costs	0.41	0.28	0.28	1.54	1.50	1.54	2.39	2.37	2.42
Medical and Industrial Isotope Transportation (annual)	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73

Key: SRS = Savannah River Site; RPL/306-E = Radiochemical Processing Laboratory and Hanford 300 Area Building 306-E.

a. Annual operating costs are an average of FFTF operating costs using onsite mixed oxide fuel (MOX) = $56.2 million, German MOX fuel = $56.7, highly enriched uranium (HEU) fuel = $63.9 million.

b. Options 1, 2, and 3 assume FFTF would use onsite MOX, German MOX, and then HEU fuel during operations. Options 4, 5, and 6 assume FFTF would use onsite MOX and then HEU fuel during operations.

c. Alternative 1 annual operating costs include an average of the FFTF operating costs.

Note: Shaded area indicates that no costs would be incurred under that alternative cost element.

- Under the No Action Alternative, FFTF would be maintained in its current standby mode at a cost of \$40.8 million per year. The No Action Alternative would also include the annual purchase of 5 kilograms (11 pounds) of Russian plutonium-238 at an assumed annual cost of \$8.84 million per year. Additional costs would depend on which option is chosen under the No Action Alternative. Option 1 would only incur the cost of maintaining FFTF in standby and the purchase of plutonium-238 from Russia. Options 2, 3, or 4 would involve the transport of neptunium-237 from SRS to REDC, CPP-651, or FMEF for long-term storage (costing \$17 to 19 million for storage modifications and startup at REDC and FMEF and \$2 million at CPP-651, which has existing storage capacity). Annual operating costs at all three storage sites would be approximately \$1.5 to 2.6 million per year. The total costs of transporting neptunium-237 from SRS to storage facilities is a function of distance and would vary from \$1.4 million for transport to REDC to \$7.1 to 8.5 million to CPP-651 or FMEF, respectively.

- Alternative 2 would combine the use of existing irradiation facilities (ATR, ATR in combination with HFIR, or a CLWR) with the choice of three processing facilities (REDC, FDPF, or FMEF) to provide nine different options for producing plutonium-238. FFTF would be deactivated at a cost of \$281 million constituting the major cost element of all options under Alternative 2. In addition, the following costs would be incurred:

  – Processing facility modification costs would be about \$37 million for FDPF; \$51 million for REDC; and \$73 million for FMEF (for the addition of most process flowsheet items of equipment, within existing plant and services) for Options 1, 2, 3, 7, 8, and 9. An additional cost of \$4 million for additional facility modifications was estimated for REDC and FDPF to fabricate stainless steel targets for the CLWR under Options 4, and 5.

  – Processing facility operating costs would be about \$7 to 8 million per year for REDC and FDPF and \$15 million per year for FMEF for Options 1, 2, 3, 7, 8, and 9. An additional cost of \$3 million was estimated for REDC, FDPF, and FMEF for the fabrication of stainless steel targets for the CLWR under Options 4, 5, and 6.

  – Irradiation charges would be \$8 million per year for ATR and ATR in combination with HFIR, and \$5 million per year for the CLWR.

  – Total transportation costs for the shipment of neptunium-237 from SRS to processing facilities would be the same as previously described for the No Action Alternative. Differences in annual plutonium-238 production shipping and handling costs between the options are due to distance, the location of the irradiation facility, and the number of shipments. All shipments to and from irradiation facilities under this alternative would be by commercial truck.

- Alternative 5 would involve the deactivation of FFTF, at a cost of \$281 million.

The sum of all facility modification costs for the nonexpanded infrastructure alternatives would be \$0 to 19 million for the No Action Alternative; \$320 to 374 million for Alternative 2; and \$281 million for Alternative 5. The sum of all annual facility operating costs (less transportation) for this program would be \$50 to 52 million for the No Action Alternative; \$15 to 23 million for Alternative 2; and \$0 for Alternative 5.

Expanded Infrastructure Alternatives

A summary of the estimated costs of the expanded infrastructure alternatives (Alternatives 1, 3, and 4 of the NI PEIS) is presented in Table S–3. Capital costs (costs of either modifying existing facilities or constructing new facilities), costs for permanently deactivating FFTF (where appropriate), annual operating costs, and transportation costs are presented for irradiation and processing facilities.

With respect to irradiation facilities, which constitute the major cost element of these alternatives, it can be seen that:

- Capital costs would be in the order of $300 million for Alternative 1 (FFTF restart) and Alternative 4 (construction of a new research reactor), and more than $1 billion for Alternative 3 (construction of new accelerators). An additional burden of $281 million would be placed on Alternatives 3 and 4 for FFTF deactivation costs because these alternatives involve the construction of new facilities. Alternative 1, FFTF restart, would not incur this cost.

- The estimated annual costs of operating the irradiation facilities would be: $25 million per year for the new research reactor in Alternative 4; $45 million per year for the accelerators in Alternative 3; and $59 to 64 million per year for FFTF in Alternative 1.

It can also be seen that the other types of facilities used in the expanded infrastructure alternatives (isotope processing facilities and support facilities that fabricate targets for irradiation and chemically process irradiated targets to recover, package, and ship isotopes) are specific to the production of either (1) plutonium-238, or (2) medical and industrial isotopes.

- Costs of modifying REDC, FDPF, or FMEF to support plutonium-238 production, together with startup costs, would range from $37 to 73 million. The lower end of this range of front-end costs represents investments in REDC and FDPF, which have been built. FMEF has not been fully equipped nor operated, and would therefore require the higher modification costs to bring this facility online. Similarly, the annual operating costs for these facilities, would range from about $7 to 18 million per year, due to the availability of shared resources that can reduce operating costs, compared to a nonoperating facility like FMEF. An additional cost of $4 million for additional facility modifications at REDC and FDPF and $3 million operating costs at REDC, FDPF, and FMEF was estimated for the fabrication of stainless steel targets for the FFTF under Alternative 1.

- The mission to produce medical and industrial isotopes and expand nuclear research and development capabilities would be supported by either the modification of existing operational facilities at Hanford under Alternative 1 (RPL/Building 306–E or FMEF) or the construction of a new facility supporting either new accelerators (Alternative 3) or a new research reactor (Alternative 4). The investment for modifications or construction and startup would amount to about $29 to 37 million for the Hanford facilities and $71 million for a newly constructed processing support facility. Annual operating costs would be lower for the two existing facilities compared to a new processing support facility ($12 to 13 million per year for RPL/Building 306–E or FMEF and $23 million per year for a new processing support facility).

Transportation costs for the expanded infrastructure alternatives would be higher for the plutonium-238 production mission than the medical and industrial isotope mission, due to distances traveled, (e.g., REDC at ORNL to FFTF at Hanford versus shipping to the nearest air freight terminal) the number of shipments, and the cost of secure shipments. Differences in annual plutonium-238 production shipping and handling costs between the three alternatives are due to the cost of secure transport versus commercial truck and the number of shipments. Under Alternative 1, commercial trucks would be used to transport neptunium targets between processing facilities and FFTF. Alternative 3 would have the fewest number of shipments but requires the use of secure transport. Alternative 4 would have the same number of shipments and nearly the same shipping and handling costs as Alternative 1, but would require the use of secure transport to ship fabricated neptunium-237 targets from processing facilities to the new research reactor. The difference in the total costs of shipping neptunium-237 from the Savannah River Site (SRS) to plutonium-238 processing facilities is a function of distance from SRS. These costs would range from a low of $1.4 million per year for REDC to about $7 to 8 million per year for FDPF and FMEF. By comparison, transportation costs in medical and industrial isotope production (involving intrasite transfers of relatively small targets and offsite transfers to the nearest air freight terminal) would amount to $0.73 million per year for each alternative.

The sum of all facility modification costs in the expanded infrastructure alternatives would be $385 to 424 million for Alternative 1; $1,485 to 1,521 million for Alternative 3; and $702 to 737 million for Alternative 4. The sum of all annual facility operating costs (less transportation) would be $82 to 90 million per year for Alternative 1; $75 to 84 million per year for Alternative 3; and $55 to 64 million per year for Alternative 4.

S.4 RISK ANALYSIS OF COST ESTIMATES

Although several types of contingencies can be defined, in general, a contingency refers to the cost that must be added to a base estimate to account for "unknown" costs. Two broad types of contingencies have been identified by Los Alamos National Laboratory (LANL) in the conceptual design report for a high-energy tritium production linear accelerator (LANL 1997). The most common type of contingency is an allowance for indeterminates, such as uncertainties in time, materials, or equipment items which may have inadvertently been omitted from the estimate. It should also be noted that the quality of the design basis for the development of the cost estimate is often a determinant of the magnitude of this type of contingency (Peters and Timmerhaus 1991). The Contingencies and Uncertainties columns in **Table S–4** reflect these types of uncertainties. A second type of contingency, often termed "risk contingency," is particularly applicable to projects involving new technologies (e.g., projects which require the preparation of cost estimates while nuclear research and development is still in progress). This contingency covers the cost effects of unforeseen design changes, altered performance requirements, or major schedule delays due to developmental problems. The Technical Risk and Schedule Risk columns in Table S–4 are indicative of risk contingency considerations.

The contingencies listed in Table S-4 that apply to the costs of the alternatives can be considered under these definitions:

No Action Alternative—Alternative cost involves little or no contingencies, technical or schedule risk, as no action is being taken other than the purchase and transport of Russian plutonium-238 to LANL and transport of neptunium-237 from SRS to long-term storage facilities at either REDC, CPP-651, or FMEF. There is a high uncertainty regarding the future purchase price for Russian plutonium-238 that could significantly affect the current estimated cost of this alternative. The current estimate for the cost for purchasing Russian plutonium-238 assumed that the contract price would be extended using the negotiated annual escalation rate of 3.5 percent for the duration of the project planning period described in the NI PEIS. The contract for the purchase of Russian plutonium-238 is in year eight, with two years remaining (DOE 1997). Beyond the last two years of the contract, the future price of Russian plutonium-238 is unknown.

Alternative 1: Restart FFTF—This alternative uses existing facilities and proven technologies, which implies relatively low contingencies (in the order of 10 to 20 percent), which is customary for this type of operation. The potential exists for schedule delays in the neptunium-237 and medical and industrial isotope stainless steel target development for FFTF. The schedule risk is considered low, because it was assumed that neptunium-237 and medical and industrial isotope target development and testing would be accomplished during FFTF startup. However, some schedule risk would remain if stainless steel targets should fail during testing or not meet performance requirements during target evaluation prior to isotope production.

Table S–4 Risk Analysis of Cost Estimates

Alternatives	*Contingencies*	*Uncertainties*	*Technical Risk*	*Schedule Risk*	*Discussion*
No Action	Low range	High	None	Low	Uncertainty: cost of Russian plutonium-238
Alternative 1: Restart FFTF	Low range	Low	None	Low	Schedule risk: neptunium-237 and medical and industrial isotope target development
Alternative 2: Use Only Existing Operational Facilities					
ATR and HFIR	Low range	Low	None	Low	Existing technology
CLWR	Moderate range	Moderate	Low	High	Schedule risk: neptunium-237 target development. Uncertainties: proprietary irradiation services costs and unknown target development cost
Alternative 3: Construct New Accelerator(s)					
High-energy linear accelerator	High range	High	High	Very high	Contingency: factor associated with preconceptual design and target/blanket development. Uncertainty: technology in development for this application. Schedule risks: target/blanket shipping cask development and certification
Low-energy cyclotron accelerator	Low range	Low	None	Low	Proven technology
Alternative 4: Construct New Research Reactor	High range	Moderate	Low	Moderate	Contingency: factor associated with preconceptual design, capability risk. Schedule risk: neptunium-237 target development
Alternative 5: Deactivate FFTF	Low range	None	None	Low	None

Alternative 2: Use Only Existing Operational Facilities—This alternative should have a low contingency of 20 percent or less because of existing technology. This alternative presents no technological requirements for modifications to existing operational facilities for the production of isotopes or the use of new technologies.

CLWR use is considered a low technological risk because it is a proven technology and an ongoing operation. However, the schedule risk is considered high because of uncertainties associated with the development of neptunium-237 targets for a CLWR (i.e., neptunium-237 target development, testing, and evaluation would have to fit in with the CLWR refueling cycle). If the neptunium-237 target fails during testing or does not meet performance requirements during target evaluation, additional target testing could not occur until the next refueling cycle (generally, another 18 months). CLWR irradiation services costs are also uncertain due to the proprietary nature of the industry.

Alternative 3: Construct New Accelerator(s)—This alternative involves the use of high-energy linear accelerator technology for the production of neutrons via spallation for isotope production. This technology places Alternative 3 in an area of high technological and schedule risks, and of high contingency factors in several areas of component development for the application of high-energy linear acceleration for plutonium-238 production.

Conversely, low-energy cyclotron accelerator use for the production of medical and industrial isotopes is a low-cost, proven technology, is currently used commercially, and has little or no schedule risk.

Alternative 4: Construct New Research Reactor—This alternative involves the use of proven research reactor technology, which implies low risk; however, the very nature of the preconceptual design requires that a high level of contingency be applied to the construction cost estimate and operating costs. The schedule risk for neptunium-237 target development is considered moderate, because even though the new research reactor design is based on proven research reactor and fuel technologies, it is preconceptual. Like FFTF, it was assumed that neptunium-237 and medical and industrial isotope target development, testing, and evaluation would be accomplished during construction and startup of the new research reactor. Unlike the CLWR, targets can be pulled from the new research reactor core at any time during testing for evaluation.

Alternative 5: Deactivate FFTF—This alternative involves only the deactivation of the FFTF reactor, which is currently in standby mode; except for uncertainties associated with the disposal of the sodium coolant, the deactivation of FFTF poses little or no technological risk and has a low-cost contingency.

1.0 OVERVIEW

1.1 INTRODUCTION

In the NI PEIS (DOE 2000), DOE identifies potential alternatives for the expanded production of isotopes and the role of FFTF. Estimates and comparisons of the program cost of each alternative presented in the NI PEIS were made in this Cost Report. In addition, this report allows DOE to include consideration of estimated program costs in the decision-making process, and may provide a basis for initial planning for the Record of Decision.

The costs associated with five alternatives and a No Action Alternative are evaluated in this Cost Report. The alternatives are described briefly in Section 1.3 of this report and in more detail in the NI PEIS (DOE 2000).

This Cost Report is divided into three sections and four appendices, as follows:

- Section 1 contains the introduction, some background, a description of the alternatives, the methodology used to estimate and identify costs, and a discussion of assumptions.

- Section 2 introduces the cost estimates for each cost element for each alternative presented in the NI PEIS.

- Section 3 discusses the compilation of cost estimates and potential revenues from the sale of medical and industrial isotopes.

- Appendices A, B, and C present the basis for estimating the cost of constructing and operating accelerators, a research reactor, and new processing support facilities, respectively.

- Appendix D provides the information used to estimate transportation costs.

1.2 BACKGROUND

Under the authority of the Atomic Energy Act of 1954, as amended, DOE is responsible for ensuring the availability of isotopes for medical, industrial, and research applications; meeting the nuclear material needs of other Federal agencies; and undertaking nuclear research and development activities related to development of nuclear power for civilian use.

To meet these responsibilities, DOE maintains nuclear infrastructure capabilities that support various missions in areas such as nuclear materials production and testing, and nuclear research and development activities related to civilian applications of nuclear power. These infrastructure capabilities include research and test facilities such as research reactors and accelerators used for steady-state irradiation of materials to produce radionuclides, as well as shielded “hot cell” and glovebox facilities used to prepare materials for testing and/or to handle postirradiation materials. An additional component of this infrastructure is the highly trained workforce that specializes in performing complex tasks that have been learned and mastered over the life of these facilities.

Over the years, DOE’s nuclear facility infrastructure has diminished because of the shutdown of aging facilities; recent examples are the High Flux Beam Reactor at Brookhaven National Laboratory, New York, and the Cyclotron Facility at Oak Ridge National Laboratory, Tennessee. This, in turn, has hampered DOE’s ability to satisfy increasing demands in various mission areas. To continue to maintain sufficient irradiation facilities to meet its obligations under the Atomic Energy Act, DOE must assess the need for expansion of its existing nuclear infrastructure in light of its commitments to ongoing programs, its commitments to other agencies for nuclear materials support, and its role in supporting nuclear research and development programs to maintain the viability of civilian nuclear power as one of the major energy sources available to the United States. [The proposed expansion of nuclear infrastructure capabilities is in response to the programmatic needs of DOE's Office of Nuclear Energy, Science and Technology and does not include programmatic needs of other program offices within DOE, including those of the Office of Science.]

DOE recognizes that adequate nuclear research reactor, accelerator, and associated processing support facilities must be available to implement and maintain a successful nuclear energy program. As demand continues to increase for steady-state irradiation sources needed for isotope production and nuclear research and development, DOE's nuclear infrastructure capabilities to support this demand have not improved. To continue meeting its responsibilities under the Atomic Energy Act and to satisfy projected increases in the future demand for isotope products and irradiation services, DOE proposes to enhance its existing nuclear facility infrastructure to provide for: (1) production of isotopes for medical, research, and industrial uses, (2) production of plutonium-238 for use in advanced radioisotope power systems for future NASA space exploration missions, and (3) support of the Nation's nuclear research and development needs for civilian applications.

1.3 DESCRIPTION OF ALTERNATIVES

The alternatives evaluated in this Cost Report involve the combination of facilities available for the tasks required in the expanded production of isotopes. The facilities fall generally into two categories: (1) buildings containing hot cells and shielded gloveboxes in which neptunium-237 would be stored and isotopes would be fabricated into targets and chemically processed to separate medical, industrial, and plutonium-238 isotope products; and (2) the reactors/accelerators in which targets would be irradiated. **Table 1–1** presents the alternatives and options evaluated in the NI PEIS.

No Action Alternative

Under the No Action Alternative (maintain status quo), FFTF would be maintained in standby status. DOE would continue its medical and industrial isotope production and nuclear research and development activities at the current operating levels of existing facilities. DOE would not establish a domestic plutonium-238 production capability, but could, instead, continue to purchase Russian plutonium-238 to meet the needs of future U.S. space missions. For the cost analysis purpose, DOE assumed that it would continue to purchase plutonium-238 to meet space mission needs. A consequence of a No Action decision would be the need to determine the future of the neptunium-237 stored at SRS. If DOE decides not to establish a domestic plutonium-238 production capability in the future, the neptunium-237 would have no programmatic value and would be disposed of. Conversely, if DOE decides to maintain the capability to establish a domestic plutonium-238 capability in the future, the inventory of neptunium-237 would be transported from SRS to another DOE facility for long-term storage. Thus, the following four options are identified under the No Action Alternative:

- **Option 1.** DOE would reconsider its stabilization strategy for the neptunium-237, currently stored in solution form at SRS, possibly leading to final disposition. The current plan is to stabilize the material to an oxide, as described in the Supplemental Record of Decision for the SRS *Final Environmental Impact Statement, Interim Management of Nuclear Materials* (DOE 1995; 62 FR 61099, 1997). The cost associated with Option 1 is not part of this cost analysis.

Table 1–1 Alternatives and Options Evaluated in the NI PEIS

			Plutonium-238 Production Mission		*Medical and Industrial Isotopes Production and Nuclear Research and Development Mission*	
	Option Number	*Irradiation Facility*	*Storage Facility*	*Target Fabrication and Processing Facility*	*Storage Facility*	*Target Fabrication and Processing Facility*
No Action Alternative	1	–	–	–	–	–
	2	–	REDC	–	–	–
	3	–	CPP–651	–	–	–
	4	–	FMEF	–	–	–
Alternative 1: Restart FFTF	1	FFTF [a]	REDC	REDC	RPL/306–E	RPL/306–E
	2	FFTF [a]	FDPF/CPP–651	FDPF	RPL/306–E	RPL/306–E
	3	FFTF [a]	FMEF	FMEF	FMEF	FMEF
	4	FFTF [b]	REDC	REDC	RPL/306–E	RPL/306–E
	5	FFTF [b]	FDPF/CPP–651	FDPF	RPL/306–E	RPL/306–E
	6	FFTF [b]	FMEF	FMEF	FMEF	FMEF
Alternative 2: Use Only Existing Operational Facilities	1	ATR	REDC	REDC	–	–
	2	ATR	FDPF/CPP–651	FDPF	–	–
	3	ATR	FMEF	FMEF	–	–
	4	CLWR	REDC	REDC	–	–
	5	CLWR	FDPF/CPP–651	FDPF	–	–
	6	CLWR	FMEF	FMEF	–	–
	7	HFIR and ATR	REDC	REDC	–	–
	8	HFIR and ATR	FDPF/CPP–651	FDPF	–	–
	9	HFIR and ATR	FMEF	FMEF	–	–
Alternative 3: Construct New Accelerator(s)	1	New	REDC	REDC	New [c]	New [c]
	2	New	FDPF/CPP–651	FDPF	New [c]	New [c]
	3	New	FMEF	FMEF	New [c]	New [c]
Alternative 4: Construct New Research Reactor	1	New	REDC	REDC	New [c]	New [c]
	2	New	FDPF/CPP–651	FDPF	New [c]	New [c]
	3	New	FMEF	FMEF	New [c]	New [c]
Alternative 5: Permanently Deactivate FFTF (with no new missions)	–	–	–	–	–	–

Key: RPL/306-E = Radiochemical Processing Laboratory and Hanford 300 Area Building 306-E.

a. Hanford FFTF would start up and operate with onsite and German mixed oxide (MOX) only fuel and then highly enriched uranium (HEU) fuel.

b. Hanford FFTF would start up and operate with only the onsite MOX fuel and then highly enriched uranium (HEU) fuel.

c. The new facility would not be required if a DOE site with available support capability and infrastructure is selected.

- **Options 2 through 4.** The neptunium-237 oxide would be transported from SRS to one of three candidate DOE facilities. Option 2 would provide storage at ORNL's REDC facility, Option 3 at INEEL's CPP-651, and Option 4 at Hanford's FMEF.

Alternative 1—Restart FFTF

Under Alternative 1, FFTF would be restarted and operated. FFTF would be used to irradiate targets for medical and industrial isotope production, plutonium-238 production, and nuclear research and development irradiation requirements. Ongoing operations associated with isotope production missions at existing facilities would continue.

Targets for medical and industrial isotope production would be fabricated in one or more facilities at Hanford. Target material would typically be acquired from ORNL, where enrichment processes are conducted to produce high-purity target material suitable for medical isotopes production. The targets would be irradiated at FFTF and then returned to the fabrication facility for postirradiation processing. From there, the isotope products would be sent directly to commercial pharmaceutical distributors.

Targets for plutonium-238 production would be fabricated in one of three candidate facilities at ORNL, INEEL, or Hanford. The material needed for target fabrication (neptunium-237) would be transported from the fabrication facilities. The nonirradiated targets would be transported and irradiated at FFTF and transported back to the fabricating facilities for postirradiation processing. The separated plutonium-238 would be transported to LANL for fabrication into heat sources for radioisotope power systems.

Six options identified under this alternative are associated with the type of nuclear fuel to be used for FFTF operations and the specific facilities to be used for target fabrication and processing. The first three options (Options 1 through 3) would involve operating FFTF with onsite and German mixed oxide (MOX) fuel and then highly enriched uranium (HEU) fuel. The last three options (Options 4 through 6) would involve operating FFTF with only onsite MOX fuel and then HEU fuel. [FFTF is currently designed to operate using MOX fuel (i.e., plutonium-uranium), however, it can also be operated using HEU fuel. FFTF has an onsite supply of MOX fuel for operation at the 100-megawatt level proposed for the mission. When this onsite fuel is depleted, FFTF may continue to use MOX fuel or may switch to a reactor core of HEU fuel. DOE believes that an additional supply of MOX fuel would be available from Germany under favorable economic terms (i.e., no charge for the fuel). The fuel would be reconfigured into assemblies suitable for irradiation at FFTF before shipment to the United States. That is why the NI PEIS evaluates FFTF operation for the two reactor core configurations.]

The options, as they relate to storage, fabrication, postirradiation processing, and transportation, are discussed below.

- **Options 1 and 4.** REDC at ORNL would be used to fabricate and process the neptunium-237 targets required for plutonium-238 production. The neptunium-237 transported from SRS to ORNL would be stored in REDC. The plutonium-238 product would be transported from ORNL to LANL. Hanford's RPL and 300 Area Building 306–E (RPL/306–E) facilities would be used to fabricate and process targets for medical and industrial isotope production and for nuclear research and development, as well as to store the materials needed to fabricate these targets.

- **Options 2 and 5.** FDPF at INEEL would be used to fabricate and process the neptunium-237 targets for plutonium-238 production. The neptunium-237 transported from SRS to INEEL would be stored in FDPF or CPP–651. The plutonium-238 product would be transported from INEEL to LANL. Hanford's RPL/306–E facilities would be used to fabricate and process targets for medical and industrial isotope production and for nuclear research and development, as well as to store the materials needed to fabricate these targets.

- **Options 3 and 6.** FMEF at Hanford would be used to fabricate and process both neptunium-237 targets for plutonium-238 production and the targets for medical and industrial isotope production, as well as supporting nuclear research and development. The neptunium-237 transported from SRS to Hanford and the other target materials transported from other offsite facilities to Hanford would be stored in FMEF. The plutonium-238 product would be transported from Hanford to LANL for fabrication into heat sources for radioisotope power systems.

Alternative 2—Use Only Existing Operational Facilities

Under Alternative 2, DOE would use existing operating DOE reactors (ATR, HFIR) or a U.S. CLWR to produce plutonium-238 for future space missions. Medical and industrial isotope production and nuclear research and development support in currently operating DOE reactors and accelerators would continue at the No Action Alternative levels. Alternative 2 includes the permanent deactivation of FFTF.

Targets for plutonium-238 production would be fabricated in one of three facilities at ORNL, INEEL, or Hanford. The material needed for target fabrication (neptunium-237) would be transported from SRS to the fabrication facilities. The targets would be irradiated at existing reactor facilities (HFIR, ATR, or a CLWR) and would be transported back to the fabricating facilities for postirradiation processing.

Under Alternative 2, nonirradiated targets, irradiated targets, and processed materials would be transported between the locations selected for storage, target fabrication, target irradiation, and postirradiation processing, and the plutonium-238 product would be transported to LANL.

Nine options are identified under this alternative. Options 1 through 3 involve the irradiation of targets in ATR at INEEL. Options 4 through 6 involve the irradiation of targets in a generic CLWR. Options 7 through 9 involve the irradiation of targets in both INEEL's ATR and ORNL's HFIR. These options, as they relate to the associated target fabrication, postirradiation processing, and transportation activities, are discussed below.

- **Option 1.** REDC at ORNL would be used to store the neptunium-237 transported from SRS to ORNL and to fabricate and process the targets (irradiated at ATR). Option 1 also involves transportation of the neptunium-237 targets from ORNL to INEEL for irradiation in ATR, transportation of the irradiated targets from INEEL back to ORNL for postirradiation processing, and subsequent transportation of the plutonium-238 product from ORNL to LANL following postirradiation processing.

- **Option 2.** FDPF at INEEL would be used to store the neptunium-237 transported from SRS to INEEL and to fabricate and process the targets (irradiated at ATR). CPP–651 would also be used for storage. Option 2 also involves transportation of the plutonium-238 product from INEEL to LANL following postirradiation processing.

- **Option 3.** FMEF at Hanford would be used to fabricate and process the targets (irradiated at ATR) and to store the neptunium-237 transported from SRS to Hanford. Option 3 also involves transportation of the neptunium-237 to Hanford for target fabrication, transportation of the targets from Hanford to INEEL for irradiation, transportation of the irradiated targets back to Hanford for postirradiation processing in FMEF, and subsequent transportation of the plutonium-238 product from Hanford to LANL.

- **Option 4.** REDC at ORNL would be used to store the neptunium-237 transported from SRS to ORNL and to fabricate and process the targets (irradiated at a generic CLWR). Option 4 also involves transportation of the neptunium-237 targets from ORNL to the generic CLWR location for irradiation, transportation of the irradiated targets back to ORNL for postirradiation processing, and transportation of the plutonium-238 product from ORNL to LANL.

- **Option 5.** FDPF at INEEL would be used to store the neptunium-237 transported from SRS to INEEL and to fabricate and process the targets (irradiated at a generic CLWR). CPP–651 would also be used for storage. In addition, Option 5 involves transportation of the neptunium-237 targets from INEEL to the generic CLWR location for irradiation, transportation of the irradiated targets back to INEEL for postirradiation processing, and transportation of the plutonium-238 product from INEEL to LANL.

- **Option 6.** FMEF at Hanford would be used to store the neptunium-237 transported from SRS to Hanford and to fabricate and process the targets (irradiated at a generic CLWR). Option 6 also involves transportation of neptunium-237 to Hanford for target fabrication, transportation of the targets from Hanford to the generic CLWR location for irradiation, transportation of the irradiated targets back to Hanford for postirradiation processing, and transportation of the plutonium-238 product from Hanford to LANL.

- **Option 7.** REDC at ORNL would be used to store the neptunium-237 transported from SRS to ORNL and to fabricate and process the targets (irradiated at ATR and HFIR). Option 7 also involves transportation of the neptunium-237 targets from ORNL to the reactors for irradiation, transportation of the irradiated targets back to ORNL for processing, and transportation of the plutonium-238 product from ORNL to LANL.

- **Option 8.** FDPF at INEEL would be used to store the neptunium-237 transported from SRS to INEEL and to fabricate and process the targets (irradiated at ATR and HFIR). CPP–651 would also be used for storage. Option 8 also involves transportation of the neptunium-237 targets from INEEL to the reactors for irradiation, transportation of the irradiated targets back to INEEL for postirradiation processing, and transportation of the plutonium-238 product from INEEL to LANL.

- **Option 9.** FMEF at Hanford would be used to store the neptunium-237 transported from SRS to Hanford and to fabricate and process the targets (irradiated at ATR and HFIR). Option 9 also involves transportation of neptunium-237 to Hanford for target fabrication, transportation of the targets from Hanford to the reactors for irradiation, transportation of the irradiated targets back to Hanford for postirradiation processing, and transportation of the plutonium-238 product from Hanford to LANL.

Alternative 3—Construct New Accelerator(s)

Under Alternative 3, one or two new accelerators could be used for target irradiation. Preconceptual designs have been developed for high and low-energy accelerators. The high-energy accelerator would support the plutonium-238 production mission and the nuclear research and development mission. The low-energy accelerator would support the medical and industrial isotope production mission and the nuclear research and development mission. The Cost Report includes the cost for the construction and operation of both accelerators.

The targets for plutonium-238 production would be fabricated in one of the three candidate facilities at ORNL, INEEL, or Hanford. The material needed for the target fabrication (neptunium-237) would be transported from SRS to the fabrication facilities. The targets would be irradiated at the high-energy accelerator facility and transported back to the target fabrication facilities for postirradiation processing.

Targets for medical and industrial isotope production would be fabricated in a new processing support facility located at the same site as the low-energy accelerator. The targets would be irradiated in the low-energy accelerator and returned to the new processing support facility for postirradiation processing. Because Alternative 3 is evaluated at a generic DOE site, the Cost Report assumed that a new processing support facility would be required to support operation of the low-energy accelerator and its missions and the high-energy accelerator nuclear research and development mission if both accelerators are located on the same site. However, it is highly unlikely that DOE would consider locating either accelerator on a DOE site that does not have existing infrastructure capable of supporting all or most of the proposed mission requirements.

Under Alternative 3, nonirradiated targets, irradiated targets, and processed materials would be transported between the locations selected for storage, target fabrication, target irradiation, postirradiation processing, and the final destination of the plutonium-238. Alternative 3 also would include decontamination and decommissioning of the new accelerator(s) and the new processing support facility when the missions are over, as well as deactivation of FFTF at Hanford. (The cost of decontaminating and decommissioning these facilities was not estimated for this Cost Report.)

The three options under this alternative, as they relate to the associated target fabrication, postirradiation processing, and transportation activities, are discussed below.

- **Option 1.** REDC at ORNL would be used to fabricate and process the neptunium-237 targets required for plutonium-238 production. The neptunium-237 transported from SRS to ORNL would be stored at REDC. The plutonium-238 product would be transported from ORNL to LANL for use in radioisotope power systems for future U.S. space missions. A new processing support facility at an existing DOE site would be used to fabricate and process the targets required for medical, industrial, and research isotope production and to store the materials needed for target fabrication.

- **Option 2.** FDPF at INEEL would be used to fabricate and process the neptunium-237 targets associated with plutonium-238 production. The neptunium-237 transported from SRS to INEEL would be stored in FDPF or CPP–651 at INEEL. The plutonium-238 product would be transported from INEEL to LANL for use in radioisotope power systems for future U.S. space missions. A new processing support facility at an existing DOE site would be used to fabricate and process the targets required to produce medical, industrial, and research isotopes and to store the materials needed for target fabrication.

- **Option 3.** FMEF at Hanford would be used to fabricate and process the neptunium-237 targets for plutonium-238 production. The neptunium-237 transported from SRS to Hanford would be stored in FMEF. The plutonium-238 product would be transported from Hanford to LANL. A new processing support facility at an existing DOE site would be used to fabricate and process the targets required for the production of medical, industrial, and research isotopes and to store the materials needed for target fabrication.

Alternative 4—Construct New Research Reactor

Under Alternative 4, a new research reactor would be used for target irradiation. The new research reactor, to be constructed at an existing DOE site, would be used to irradiate all targets (i.e., for plutonium-238 production, isotopes for medical and industrial uses, and materials testing for nuclear research and development).

The targets for plutonium-238 production would be fabricated in one of the three candidate facilities at ORNL, INEEL, or Hanford. The material needed for the target fabrication (neptunium-237) would be transported from

SRS to the fabrication facilities. The targets would be irradiated at the new research reactor facility and transported back to the target fabrication facilities for postirradiation processing.

Targets for medical and industrial isotope production would be fabricated in a new processing support facility located at the same site as the new research reactor. The targets would be irradiated in the new research reactor and returned to the new processing support facility for postirradiation processing.

Because Alternative 4 is evaluated at a generic DOE site, the Cost Report assumed that a new processing support facility would be required to support operation of the new research reactor and its missions. However, it is highly unlikely that DOE would consider locating the new research reactor on a DOE site that does not have existing infrastructure capable of supporting all or most of the proposed medical and industrial isotope production and nuclear research and development mission requirements.

Under Alternative 4, nonirradiated targets, irradiated targets, and processed materials would be transported between the locations selected for storage, target fabrication, target irradiation, postirradiation processing, and the final destination of the plutonium-238. Alternative 4 also would include the decontamination and decommissioning of both the new research reactor and the new processing support facility when the missions are over, as well as deactivation of FFTF at Hanford. (The cost of decontaminating and decommissioning these facilities was not estimated for this Cost Report.)

The three options under this alternative, as they relate to target fabrication, postirradiation processing, and transportation activities, are discussed below.

- **Option 1**. REDC at ORNL would be used to fabricate and process the neptunium-237 targets associated with plutonium-238 production. The neptunium-237 transported from SRS to ORNL would be stored at REDC. The plutonium-238 product would be transported from ORNL to LANL. A new processing support facility at an existing DOE site would be used to fabricate and process the targets required for the production of medical, industrial, and research isotopes and to store the materials needed for target fabrication.

- **Option 2**. FDPF at INEEL would be used to fabricate and process the neptunium-237 targets associated with plutonium-238 production. The neptunium-237 transported from SRS to INEEL would be stored in FDPF or CPP–651. The plutonium-238 product would be transported from INEEL to LANL. A new processing support facility at an existing DOE site would be used to fabricate and process the targets required for the production of medical, industrial, and research isotopes and to store the materials needed for target fabrication.

- **Option 3**. FMEF at Hanford would be used to fabricate and process neptunium-237 targets for plutonium-238 production. The neptunium-237 transported from SRS to Hanford would be stored in FMEF. The plutonium-238 product would be transported from Hanford to LANL. A new processing support facility at an existing DOE site would be used to fabricate and process the targets required for the production of medical, industrial, and research isotopes and to store the materials needed for target fabrication.

Alternative 5—Permanently Deactivate FFTF (with no new missions)

Under Alternative 5, DOE would permanently deactivate FFTF, with no new missions. Medical and industrial isotope production and nuclear research and development missions would continue at the existing operating facilities. DOE's nuclear facility infrastructure would not be enhanced.

1.4 COST METHODOLOGY AND ASSUMPTIONS

1.4.1 Methodology

The basic methodology used to estimate the cost for each alternative/option is as follows:

Work Element Identification—Each alternative/option was divided into cost elements. These elements make up the alternatives and are defined by the irradiation facilities, isotope processing facilities, and transportation activities. The cost elements for each of the alternatives are outlined in Section 1.5.

Cost Estimating—An estimate was made of the cost to complete each element. The estimate was based on data provided by candidate DOE sites for existing facilities and on preconceptual designs for proposed new facilities. Source documents containing the basic cost information are referenced in Section 4.0 in this report.

Cost Conversion to FY 2000 Dollars—Since most cost data used in the estimates originated prior to FY 2000, these cost estimates were escalated to FY 2000 dollars using an escalation factor provided by DOE's Office of Engineering and Construction Management. This escalation factor is 2.9 percent for construction expenditures and 2.1 percent for operation expenditures (Ross 2000).

1.4.2 Assumptions

Facility modification and operating costs were obtained from DOE Field and Headquarters Offices and facility contractors and have been identified here and in Section 2, Costs of Alternatives. Cost estimates were affected by the status of the facility (operating, in standby mode, not in use, or in the design stage). Assumptions regarding the extent to which facility modifications and construction would be required, existing facilities and services would be used, and how contingency factors and overhead costs were allocated also played a role in estimating costs. These assumptions are also identified in Section 2.

It was assumed that capital and operating costs submitted by DOE Field and Headquarters Offices and facility contractors were valued in the year in which the estimate was made (for the most part, FY 1999 dollars). These estimates were converted to FY 2000 dollars using the escalation factors provided by DOE's Office of Engineering and Construction Management (Ross 2000).

Further, it was assumed that the costs presented in Section 2, Cost of Alternatives, represent out-of-pocket costs to the Government; that is, they are requirements for new outlays, without costs for the use of existing equipment or facilities that may be used in the respective alternatives.

With respect to overall costs, it should be noted that, although the summary of estimated costs for alternatives and options outlined in all tables presented in this Cost Report, include site construction, modification, and operation overhead costs, they do not include any DOE administrative overhead costs. Thus, there is an implicit assumption that this cost component is normally budgeted separately and does not constitute a part of the outlays for the alternatives.

The cost estimations presented in this Cost Report that are based on preconceptual designs and approximations may contain errors upwards of 30 percent, and perhaps as much as 50 percent (Peters and Timmerhaus 1991). Therefore, these cost estimates are not recommended for use in determining budget outlays. Detailed designs and cost estimates are prerequisites for such determinations.

1.5 COST ELEMENTS

The cost elements associated with each of the alternatives are outlined below.

No Action Alternative

- FFTF in standby mode—maintain current status
- Purchase Russian plutonium-238—at current contract price escalated annually at 3.5 percent
- Neptunium-237 storage—including facility modifications, startup, and operations for each of the facilities
  - REDC
  - CPP-651
  - FMEF
- Transportation
  - Russian plutonium-238 to Los Alamos National Laboratory (LANL)—shipped from port of entry to LANL
  - Neptunium-237 from the Savannah River Site (SRS) to storage facilities (REDC, CPP-651, FMEF)

Note: The cost associated with the stabilization of neptunium-237 solution at SRS is not included in the cost estimate for any of the alternatives. This activity was addressed as a separate NEPA action in DOE's Record of Decision for the Interim Management of Nuclear Materials at SRS EIS (62 FR 61099).

Alternative 1: Restart FFTF

- FFTF restart and operation
  - Facility modifications; startup; and target development, testing, and evaluation
  - Operations, including startup, using combinations of mixed oxide (MOX) fuel and highly enriched uranium (HEU) fuel. The MOX and HEU fuel domestic transportation cost is included in the FFTF operations cost (the HEU fabrication cost is included in the annual operating cost).
- Neptunium-237 target fabrication and plutonium-238 processing—including facility modifications, startup, and operations for each of the facilities
  - REDC
  - FDPF
  - FMEF
- Medical and industrial isotope target fabrication and processing—facility modifications; startup; target development, testing, and evaluation; and operations for each of the facilities
  - RPL/306–E
  - FMEF
- Transportation
  - Neptunium-237 from SRS to target fabrication facilities, neptunium-237 targets to and from FFTF, and plutonium-238 from target processing facilities to LANL—that is, 33 shipments from SRS, 315 shipments to and from irradiation facilities, and 35 shipments to LANL
  - Medical and industrial isotopes—shipments to nearest air freight terminal

Alternative 2: Use Only Existing Operational Facilities

- FFTF deactivation
- Irradiation services for plutonium-238—including target development, testing, and evaluation for ATR and HFIR; target development, testing, and evaluation for the CLWR; and irradiation services
  - ATR
  - ATR plus HFIR
  - CLWR
- Neptunium-237 target fabrication and plutonium-238 processing—including facility modifications, startup, and operations
  - REDC
  - FDPF
  - FMEF
- Transportation
  - Neptunium-237 from SRS to target fabrication facilities, neptunium-237 targets to and from irradiation facilities (ATR, HFIR, CLWR), and plutonium-238 from target processing facilities to LANL

Alternative 3: Construct New Accelerator(s)

- FFTF deactivation
- Construct and operate new facilities
  - High-energy accelerator: design and construction; startup; target development, testing, and evaluation; operations; and decontamination and decommissioning (not estimated for this Cost Report)
  - Low-energy accelerator: design and construction; startup; target development, testing, and evaluation; operations; and decontamination and decommissioning (not estimated for this Cost Report)
  - Accelerator processing support facility: design and construction; startup; target development, testing, and evaluation; operations; and decontamination and decommissioning (not estimated for this Cost Report)
- Neptunium-237 target fabrication and plutonium-238 processing—including facility modifications, startup, target preparation and storage, and operations
  - REDC
  - FDPF
  - FMEF
- Transportation
  - Neptunium-237 from SRS to target fabrication facilities, neptunium-237 targets to and from accelerator facilities, and plutonium-238 from target processing facilities to LANL
  - Medical and industrial isotopes—shipments to nearest air freight terminal

Alternative 4: Construct New Research Reactor

- FFTF deactivation
- Construct and operate new facilities—including design and construction; startup; target development, testing, and evaluation; operations; and decontamination and decommissioning for each of the facilities (decontamination and decommissioning costs were not estimated for this Cost Report)
  - Research reactor
  - Research reactor processing support facility

- Neptunium-237 target fabrication and plutonium-238 processing—including facility modifications, startup, target preparation and storage, and operations for each of the facilities
  - REDC
  - FDPF
  - FMEF
- Transportation
  - Neptunium-237 from SRS to target fabrication facilities, neptunium-237 targets to and from the new research reactor, and plutonium-238 from target processing facilities to LANL
  - Medical and industrial isotopes—shipments to nearest air freight terminal

Alternative 5: Deactivate FFTF

- FFTF deactivation

2.0 COSTS OF ALTERNATIVES

In this section, cost estimates are presented for facility construction or modifications, operations, and for intra- and intersite transportation of materials. This section documents the cost estimates provided by DOE Field and Headquarters Offices and operating contractors, and identifies cost data used in the analyses.

Ideally, the data used in a cost report of this kind would have a common basis in terms of probable accuracy, confidence level, contingencies and other factors used in the development of cost estimates. This has not been possible, for several reasons: (1) facility modification costs and construction costs have been derived on a number of bases (ranging from detailed flowsheet-based conceptual designs, to extrapolations from preconceptual designs, to scaled estimates); (2) cost estimates have been submitted with the inclusion of a variety of contingency factors, without any consistent rationale (and in one case, without any discernable contingency at all); (3) the cost estimates have been represented as point estimates, i.e., cost ranges have not been provided, making it difficult to judge their probable accuracy in the view of the estimator.

Thus, for the reason that the cost estimates are not consistent among themselves, it is difficult to make valid comparisons between alternatives as candidates for future DOE programs, until more detailed designs permit a more consistent and accurate assessment of the probable costs. However, it is possible to assess the order-of-magnitude costs of the alternatives and to identify alternatives and options for further investigations in order to generate cost estimates of greater precision.

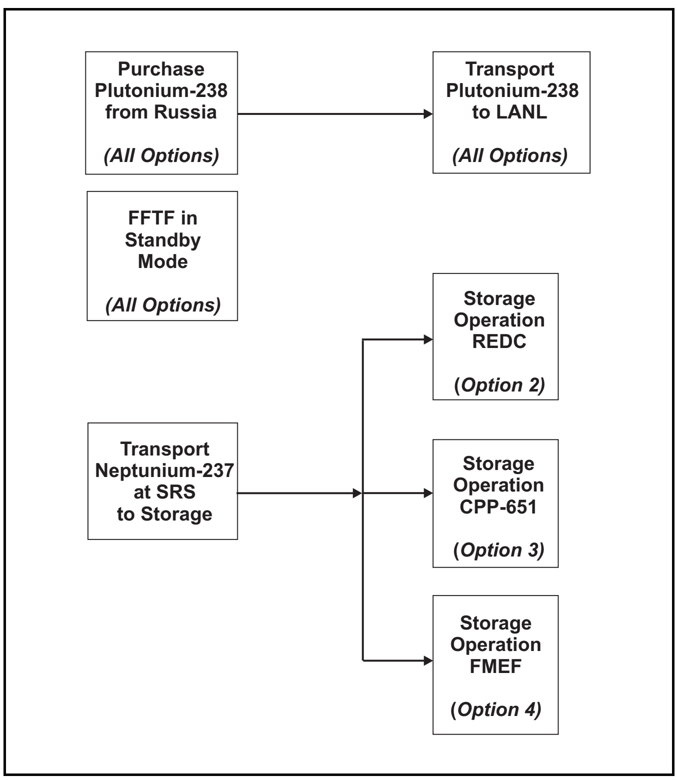

Figure 2–1 Process Flow for the No Action Alternative

2.1 NO ACTION ALTERNATIVE (FOUR OPTIONS)

Under the No Action Alternative, DOE would continue its medical and industrial isotope production and nuclear research and development activities at the current operating levels of existing facilities. Plutonium-238 would not be produced. FFTF would continue to be maintained in standby mode (all options). Plutonium-238 would be purchased from Russia and shipped to LANL (all options). Neptunium-237 stored at SRS would be transported to REDC, CPP-651, or FMEF for long-term storage (Options 2, 3 and 4, respectively). **Figure 2–1** schematically depicts these material flows and process operations for the No Action Alternative and its four options.

Cost Elements: The cost elements for all four options would include FFTF in standby mode and the purchase of Russian plutonium-238. Options 2, 3, and 4 would include storage facility modifications, startup, and operations; and transportation expenses. Transportation costs assumed 33 shipments of neptunium-237 from SRS to either REDC, CPP-651, or FMEF for long-term storage. A summary of the estimate costs associated with this Alternative is presented in **Table 2–1**.

Table 2–1 Summary of Estimated Costs for the No Action Alternative (Millions of FY 2000 Dollars)

Cost Elements	*No Action*			
Irradiation Facilities				
FFTF in standby mode (annual) (A)	40.8			
FFTF deactivation (B)				
Startup; target development, testing, and evaluation (C)				
Irradiation services charge (annual) (D)				
Russian Plutonium-238				
Purchase 5 kilograms (11 pounds) of Russian plutonium-238 (annual)	8.7 [a]			
Transport Russian plutonium-238 to LANL (annual)	0.14			
Total Annual Costs (E)	**8.84**			
Processing Facility Alternative Options	**1**	**2**	**3**	**4**
Neptunium-237 Storage and Plutonium-238 Processing Facilities		**REDC**	**CPP-651**	**FMEF**
Modifications		15.4	0.62	16.7
Startup		1.5	1.5	2.6
Subtotal modification and startup costs (F)		**16.9**	**2.12**	**19.3**
Operations (annual) (G)		1.5	1.5	2.6
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities [b]				
Modifications				
Startup				
Subtotal modification and startup costs				
Operations (annual)				
Combined Estimated Costs				
Total Costs (B+C+F)	0	16.9	2.12	19.3
Annual Costs (A+D+E+G)	49.6	51.1	51.1	52.2
Plutonium-238 Production Transportation				
Neptunium-237 from SRS (total)		1.4	7.1	8.5
Neptunium-237 targets to irradiation (annual)				
Irradiated targets to processing (annual)				
Plutonium-238 to LANL (annual)				
Total Annual Plutonium-238 Production Shipping and Handling Costs				
Medical and Industrial Isotopes to Airport (annual) [b]				

a. Based on FY 2000 contract year eight, $1.74 million per kilogram x 5 kilograms. Succeeding years' purchase price escalated at contractual 3.5 percent per year for the remaining two years of the contract.
b. DOE would continue its medical and industrial isotope production and nuclear research and development activities at the current operating levels of existing facilities.

Note: Shaded areas indicate that no costs would be incurred under that alternative and/or option.

Irradiation Facility Operating Expenses (All Options)

FFTF—The cost of maintaining FFTF in standby mode was estimated to be $40 million annually in 1999 dollars (PNNL 1999), or $40.8 million in FY 2000 dollars when escalated by 2.1 percent (Ross 2000). This cost was applied to each option in the No Action Alternative.

Purchase Russian Plutonium-238 Expenses (All Options)

The annual cost of purchasing 5 kilograms (11 pounds) of Russian plutonium-238 was estimated based on the currently negotiated price per kilogram of plutonium-238 between the United States and Russia (DOE 1997). The contracted price per kilogram of Russian plutonium-238 in contract year eight, FY 2000, is $1.74 million. The price presented in Table 2–1 is $8.7 million, based on the FY 2000 contract year eight price of $1.74 million per kilogram x 5 kilograms, for a 5-kilogram (11-pound) delivery of plutonium-238. The annual cost for transporting the Russian plutonium-238 from the port of entry to LANL, $0.14 million, was based on a single shipment of 5 kilograms (11 pounds) of plutonium-238 shipped in two safe secure trailers/safeguards transporters (SST/SGTs). The annual cost for the purchase and transport of this material, $8.84 million, would be the same for all options under the No Action Alternative.

Neptunium-237 Storage Facility Modification and Operating Expenses (Options 2, 3, and 4)

Options 2, 3, and 4 consist of receiving and storing neptunium-237 at REDC at ORNL, CPP-651 at INEEL, or FMEF in the Hanford 400 Area.

Modification of REDC was estimated to cost up to $15 million (Wham 1999b), or $15.4 million in FY 2000 dollars when escalated by 2.9 percent for construction (Ross 2000). Since acceptable storage facilities already exist at CPP-651, facility modification expenses were estimated to cost about $0.6 million ($0.62 million in FY 2000 dollars) in Option 3. FMEF storage facility modifications were estimated at $16.7 million in FY 2000 dollars (Nielsen 2000).

The estimated annual operating costs for storing neptunium-237 at REDC are $0.3 to 1.5 million per year (Wham 1999c). For conservatism, the $1.5 million ($1.53 million in FY 2000 dollars) annual cost was assumed for the REDC and CPP-651 storage options (Options 2 and 3). Operating expenses include startup and storage (Wham 1999b). This operating cost was also applied to CPP-651 at INEEL. An annual operating cost of $2.6 million was estimated for FMEF (Nielsen 2000). All of the cited operating costs are in year 2000 dollars.

Neptunium-237 Transportation Expenses (Options 2, 3, and 4)

As noted in Section 1.4, Cost Methodology and Assumptions, transportation cost estimates (Clark 2000) were based upon actual operational costs for escorted (security) shipments via SST/SGTs. The Transportation Safeguards Division of DOE's Albuquerque Operations Office was given the data for the sites, facilities, and road distances involved in intersite shipments for each option (Clark 2000). Since the Transportation Safeguards Division operating procedures are classified, the operational details relevant to the development of the cost estimates cannot be published. The transportation cost for shipping and handling neptunium-237 to the three proposed storage facilities are presented in **Table 2–2.**

Table 2–2 Transportation Costs for Neptunium-237 Shipping and Handling Under the No Action Alternative (Options 2, 3, and 4)

Option 2: SRS to REDC	$41,500 per shipment x 33 shipments	$1.3 million ($1.4 million in FY 2000 dollars)
Option 3: SRS to CPP-651	$210,700 per shipment x 33 shipments	$6.9 million ($7.1 million in FY 2000 dollars)
Option 4: SRS to FMEF	$252,300 per shipment x 33 shipments	$8.3 million ($8.5 million in FY 2000 dollars)

2.2 ALTERNATIVE 1 – RESTART FFTF (SIX OPTIONS)

Under Alternative 1, FFTF would be restarted and operated at a power level of 100 megawatts-thermal to irradiate targets for the production of medical, industrial, and plutonium-238 isotopes and to support nuclear research and development activities. The six options for Alternative 1 include two different fueling strategies for FFTF and three different sets of facilities to fabricate and process plutonium-238 targets. For each option, the facilities that would be used are explained below. **Figure 2–2** schematically depicts these material flows and process operations for Alternative 1.

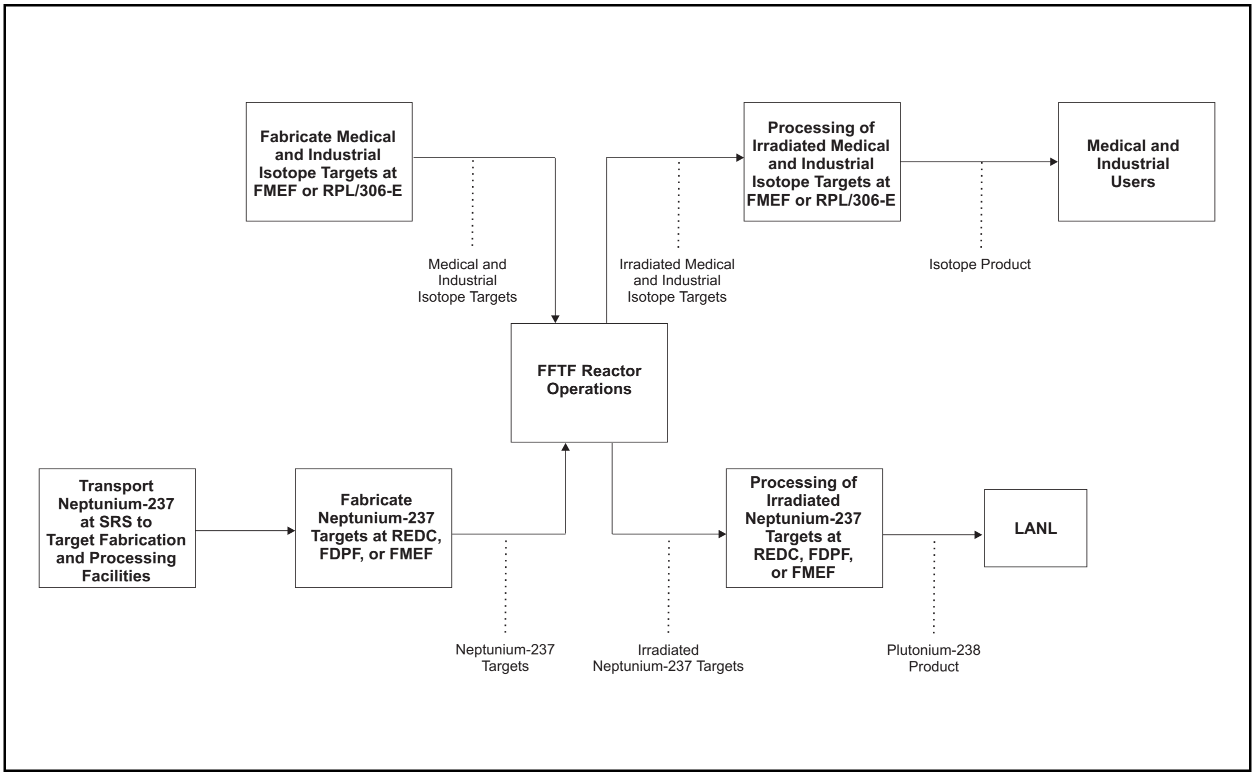

Figure 2–2 Process Flow for Alternative 1 – Restart FFTF

Cost Elements: The cost elements for this alternative would include irradiation facility costs (FFTF restart and operations); plutonium-238 processing facility costs (facility modifications and operations at REDC, FDPF, or FMEF); medical and industrial isotope/nuclear research and development processing facility costs (Hanford's Buildings RPL/306-E or FMEF); and transportation costs (plutonium-238 and medical and industrial isotope production targets and products. A summary of the estimated costs associated with Alternative 1 is presented in **Table 2–3**.

Modification Expenses—Irradiation, Plutonium-238, and Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities

Facility modification costs would be incurred for FFTF for medical, industrial, and plutonium-238 isotope production; for REDC, FDPF, and FMEF in target fabrication and processing for plutonium-238 production; and for FMEF and the Hanford RPL/306-E facilities for medical and industrial isotope production.

Table 2–3 Summary of Estimated Costs for Alternative 1 (Millions of FY 2000 Dollars)

Cost Elements		*Alternative 1: Restart FFTF*		
Irradiation Facilities				
Modification or construction		37.7		
Startup		276.3		
Subtotal Modification or Construction, and Startup Including Target Development, Testing, and Evaluation		**314**		
FFTF deactivation				
Total Irradiation Facility Costs	**(A)**	**314**		
Annual Operating Costs		Onsite MOX		56.2
		Foreign MOX [a]		56.7
Operations (annual)	(B)	HEU [b]		63.9
Processing Facility Alternative Options		**1 and 4 [c]**	**2 and 5 [c]**	**3 and 6 [c]**
Plutonium-238 Processing Facilities		**REDC**	**FDPF**	**FMEF**
Modifications or construction		45.1	31.2	62.8
Startup		10	10	10
Subtotal modification and startup costs	**(C)**	**55.1**	**41.2**	**72.8**
Operations (annual)	(D)	10.8	9.7	18.3
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities		**RPL/306-E**		**FMEF**
Modification or construction		29.4 [d]		36.8 [d]
Startup				
Subtotal modification or construction, and startup costs	**(E)**	**29.4**		**36.8**
Operations (annual)	(F)	12.1		12.9
Combined Estimated Costs				
Total Costs	(A+C+E)	398.5	384.6	423.6
Annual Operating Costs [e]	(B+D+F)	81.8	80.7	90.1
Plutonium-238 Production Transportation				
Neptunium-237 from SRS (total)		1.4	7.1	8.5
Neptunium-237 targets to irradiation (annual)		0.14	0.09	0.08
Irradiated targets to processing (annual)		0.14	0.09	0.08
Plutonium-238 to LANL (annual)		0.12	0.09	0.13
Total Annual Plutonium-238 Production Shipping and Handling Costs		**0.41**	**0.28**	**0.28**
Medical and Industrial Isotope Transportation (annual)		0.73	0.73	0.73

a. Includes $0.53 million per year for domestic transport of German MOX fuel to FFTF.
b. Includes $1.6 to 1.7 million per year for domestic transport of fabricated HEU fuel to FFTF.
c. Options 1, 2, and 3 assume FFTF would use onsite MOX, German MOX, and then HEU fuel during operations. Options 4, 5, and 6 assume FFTF would use onsite MOX, then HEU fuel during operations.
d. Startup costs included in modification costs per referenced data.
e. Annual operating costs include an average of the FFTF operating costs.

Note: Shaded area indicates that no costs would be incurred under that alternative cost element.

FFTF (All Options)—FFTF modification costs would be incurred for installing isotope systems, including Rapid Radioisotope Retrieval Systems for the production of short-lived isotopes, and Long-Term Irradiation Vehicles for the handling of targets used for the production of long-lived isotopes. In addition, FFTF would require upgrades to improve the reliability and efficiency of planned operations. As shown in Table 2–3, the total cost of facility modifications in restarting FFTF was estimated at $37.7 million for operations in FY 2000 dollars (Klos 2000).

REDC—In Options 1 and 4, modification costs at REDC necessary to store neptunium-237 received from SRS, fabricate neptunium-237 targets, and then chemically process irradiated targets were estimated at

$39.9 million ($41.1 million in FY 2000 dollars) (Wham 1999b), including contingencies. An additional $4 million investment was added for stainless steel target fabrication, resulting in an increased modification cost of $45.1 million (Wham 2000).

FDPF—In Options 2 and 5, the costs for facility modifications at FDPF, including the costs for safety documentation, equipment fabrication, and vendor-supplied target fabrication equipment, were estimated at $25.8 million (Folker 1999). This figure includes a 31.5 percent general and accounting (overhead) charge added to the equipment costs, and a 30 percent contingency factor applied to all of the capital cost components. Minor modifications to the existing storage facility at CPP-651, located a short distance from FDPF, were assumed to cost an additional $0.6 million (Folker 1999), for a total facility modification cost of $26.4 million ($27.2 million in FY 2000 dollars). An additional $4 million investment was added for stainless steel target fabrication, resulting in an increased modification cost of $31.2 million (Wham 2000) for Options 2 and 5.

FMEF—In Options 3 and 6, cost estimates for facility modifications for plutonium-238 production at FMEF were based on a production strategy document prepared for DOE (Hoyt et al. 1999), which references an earlier conceptual design report that described a 30-kilogram (66-pound) per year plutonium-238 production facility (WHC/KEHC 1990). In the production strategy document (Hoyt et al. 1999), the $77 million capital cost for FMEF estimated in the conceptual design report was scaled down to $32 million for the required throughput of 5 kilograms (11 pounds) of plutonium-238 per year, using the "six-tenths power rule" (Peters and Timmerhaus 1991) (see Appendix B.2.1). A final capital cost of $45.5 million in current-year dollars was estimated for FMEF facility modifications. By including the additional $16.7 million cost for neptunium-237 storage modifications (see costs for the No Action Alternative, Option 4), when escalated, the total cost of modifications at FMEF was estimated at $62.8 million in FY 2000 dollars. As the flow sheet in the *Summary of Strategy for Implementing Plutonium-238 Production Activities in FMEF* (Hoyt et al. 1999) provided for the fabrication of stainless steel-clad neptunium-237 targets, no additional facility modification charges were made for this purpose.

In Options 3 and 6, FMEF would also support target fabrication and processing for medical and industrial isotope production. The cost of modifying FMEF for this mission has been estimated to be $36.8 million (Nielsen 2000), in FY 2000 dollars. It was assumed for costing purposes that most isotope products would be processed in their own dedicated processing station to prevent cross-contamination, minimize equipment setup time, and provide a high level of control and product quality. This very conservative approach should result in an upper bounding facility modification cost for both of these FMEF activities.

RPL/306-E—In Options 1, 2, 4, and 5, Buildings RPL/306–E would be modified for medical and industrial isotope production at a cost of $29.4 million in FY 2000 dollars, including startup costs and a 35 percent contingency (Nielsen 2000). The modifications would apply to RPL Buildings 325 (hot and recycled target fabrication), 325A and B (for irradiated target processing, in addition to 10 laboratories in the 500 Corridor of Building 325), and 306-E (cold target fabrication).

Operating Expenses—Irradiation, Plutonium-238 and Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities

Operating expenses would be incurred by FFTF and the associated target fabrication and processing facilities. In addition, costs associated with the inter- and intrasite transportation of materials would be incurred. Medical and industrial isotope transportation costs would end with the transfer of packaged isotopes from Hanford to air freight, Tri-Cities Airport, Pasco, Washington. Plutonium-238 product transportation costs would end with delivery to LANL.

FFTF (All Options)—FFTF operation expenses under Alternative 1 would include costs associated with startup, followed by operations at a 100-megawatt power level. Operating expenses during restart were estimated to be $276.3 million (Klos 2000), in FY 2000 dollars (see Table 2–3).

The estimate of annual operating costs during operations would be strongly influenced by fuel charges. All fuel burnup charges were excluded because (1) all U.S. fuel (MOX as well as HEU) was considered to be Government-furnished material; and (2) the foreign source of MOX fuel was considered to be available, at no cost, under preliminary agreements (PNNL 1999). Therefore, the fuel component of operating costs would include commercial fabrication of HEU fuel assemblies, estimated at $4 to 6 million per year (after no-cost use of available German MOX fuel assemblies); fuel storage and handling; and spent fuel management. This cost was included in the FFTF annual operating cost estimates. Other operating cost components would include labor and materials for operations and maintenance, utilities, and engineering and technical support. The annual operating cost for FFTF, operating at 100 megawatts-thermal, was estimated at $55 million per year (or $56.2 million per year [using onsite MOX fuel] and $56.7 million per year [using German MOX fuel] in FY 2000 dollars) and $61 million per year (or $63.9 million per year in FY 2000 dollars) using commercially fabricated HEU fuel (PNNL 1999). The cost of domestic transport of German MOX and HEU fuel was included in the FFTF annual operating cost estimates (see Table 2–3). Target development costs were included with the operating costs provided by Pacific Northwest National Laboratory (PNNL).

REDC—In Options 1 and 4, annual operating costs for target fabrication and chemical processing at REDC were estimated to be $10.8 million and possibly increase in year 2000 dollars (ORNL 1999). An additional operating expense of $10 million would be added in the first year of operations in FY 2005 for startup costs (Wham 1999b), for a total of $20.8 million in FY 2000 dollars. As FFTF would require stainless steel-clad neptunium-237 targets, an additional fabrication cost of $3 million per year, was included in REDC operating costs for Alternative 1 (Wham 2000). This increment for the fabrication of stainless steel-clad neptunium-237 targets was also applied to the operating costs of FDPF and FMEF.

FDPF—In Options 2 and 5, annual operating costs at FDPF were estimated on the basis of processing 27 target batches per year, totaling $6.58 million per year ($6.7 million per year in FY 2000 dollars), including a 30 percent contingency (Folker 1999). An additional operating expense of $10 million would be added in the first year of operations for startup costs, consistent with the startup costs at REDC, for a total of $16.6 million ($16.9 million in FY 2000 dollars). An additional $3 million per year in operating costs would be required for the fabrication of stainless steel-clad neptunium-237 targets, as in the case of REDC (Wham 2000).

FMEF—In Options 3 and 6, annual operating costs at FMEF were estimated to be the same as for REDC, i.e., about $10 million per year (Hoyt et al. 1999). An additional $5 million per year was added for facility operations and maintenance support costs, resulting in a total facility operating expense of $15 million per year ($15.3 million per year in FY 2000 dollars). As in the cases of REDC and FDPF, the fabrication of stainless steel-clad neptunium-237 targets would require another $3 million per year (Wham 2000) in support of FFTF, for a total annual operating cost of $18.3 million in FY 2000 dollars. An additional operating expense of $10 million would be added in the first year of operations for startup costs, consistent with startup costs at REDC, for a total of $28.5 million in FY 2000 dollars.

The cost of operating FMEF facilities for target fabrication and medical and industrial isotope processing has been estimated to be $12.9 million per year (Nielsen 2000), in FY 2000 dollars.

Hanford RPL/306-E—Annual operating costs for target fabrication and chemical processing at RPL/306–E were estimated be $12.1 million per year in FY 2000 dollars (Nielsen 2000).

Transportation Expenses for Alternative 1

Transportation costs between facilities involved in plutonium-238 production under Alternative 1 would include 33 shipments of neptunium-237 oxide from SRS to either REDC, FDPF, or FMEF for target fabrication. In addition, annual transportation costs for plutonium-238 production would include: (1) 9 shipments of neptunium-237 targets from REDC, FDPF, or FMEF to FFTF for irradiation; (2) 9 return shipments of irradiated targets from FFTF to REDC, FDPF, or FMEF for the recovery of the plutonium-238 product and unconverted neptunium-237; and (3) 1 shipment of the plutonium-238 product from REDC, FDPF, or FMEF to LANL.

Total and annual transportation costs in FY 2000 dollars associated with plutonium-238 production for all options are presented in **Table 2–4**. The tables do not include the costs of domestic transport of German MOX fuel and fabricated HEU fuel to FFTF, after depletion of the onsite MOX inventory. As previously noted, these costs were included in FFTF operating costs.

Table 2-4 Plutonium-238 Production Transportation Costs for Alternative 1 (All Options)

Transportation Elements	*Cost Basis*	*Cost per Shipment (millions)*	*Number of Shipments*	*Total in FY 2000 Dollars (millions)*
Options 1 and 4				
Neptunium-237 to REDC	Three SST/SGTs	0.041	33	1.4
Annual Transportation Costs				
REDC neptunium-237 targets to FFTF	Commercial truck	0.016	9	0.14
FFTF-irradiated neptunium-237 targets to REDC	Commercial truck	0.016	9	0.14
REDC-separated plutonium-238 to LANL	Two SST/SGTs	0.124	1	0.12
Total annual transportation costs in FY 2000 dollars				0.41
Options 2 and 5				
Neptunium-237 to FDPF	Three SST/SGTs	0.214	33	7.1
Annual Transportation Costs				
FDPF neptunium-237 targets to FFTF	Commercial truck	0.010	9	0.09
FFTF-irradiated neptunium-237 targets to FDPF	Commercial truck	0.010	9	0.09
FDPF-separated plutonium-238 to LANL	Two SST/SGTs	0.091	1	0.09
Total annual transportation costs in FY 2000 dollars				0.28
Options 3 and 6				
Neptunium-237 to FMEF	Three SST/SGTs	0.259	33	8.5
Annual Transportation Costs				
FMEF neptunium-237 targets to FFTF	Onsite transport/handling	0.0085	9	0.08
FFTF-irradiated neptunium-237 targets to FMEF	Onsite transport/handling	0.0085	9	0.08
FMEF-separated plutonium-238 to LANL	Two SST/SGTs	0.129	1	0.13
Total annual transportation costs in FY 2000 dollars				0.28

Source: Clark 2000.

Transportation costs between facilities involved in medical and industrial isotope production would include: (1) intrasite transportation of targets fabricated in FMEF or Hanford RPL/306-E to FFTF; (2) intrasite transportation of irradiated targets from FFTF to FMEF or RPL/306-E; and (3) offsite transportation of separated and packaged isotopes from FFTF or RPL/306-E to air freight, Tri-Cities Airport, Pasco, Washington. The estimated total and annual transportation costs in FY 2000 dollars associated with medical and industrial isotope production for all Alternative 1 options are presented in **Table 2–5**.

Table 2–5 Medical and Industrial Isotope Production Annual Transportation Costs for Alternative 1 (All Options)

Transportation Elements	*Cost (Millions of FY 2000 Dollars)*
FFTF targets to FMEF or RPL/306–E	$0.26
FMEF or RPL/306–E isotopes to air freight	$0.47
Total annual transportation costs in FY 2000 dollars	$0.73

Source: PNNL 1997.

2.3 Alternative 2—Use Only Existing Operational Facilities (Nine Options)

Under Alternative 2, DOE would use existing nuclear facilities currently in operation to produce plutonium-238. FFTF would be permanently deactivated, and production of medical and industrial isotopes would continue at current operating levels of existing facilities.

Reactor operating costs under this alternative would include the deactivation of FFTF from its current standby mode, as well as irradiation services charges for neptunium-237 target irradiation at ATR at INEEL, a CLWR, or the combined use of both HFIR at ORNL and ATR. FFTF deactivation costs were applied to all options in this alternative. The total cost has been estimated to be approximately $281.2 million (Klos 2000) in FY 2000 dollars. A summary of the estimated costs associated with Alternative 2 is presented in **Table 2–6**.

Under this alternative, neptunium-237 would be shipped to REDC, FDPF, or FMEF for target fabrication and processing. These facilities would fabricate and ship neptunium-237 targets to a reactor for irradiation. After irradiation, the targets would be shipped back to REDC, FDPF, or FMEF for chemical processing to recover the plutonium-238 product and recycle unconverted neptunium-237 before shipping the plutonium-238 product to LANL. These material flows and process operations for Alternative 2 and its nine options are schematically depicted in **Figure 2–3**.

2.3.1 Options 1, 2, and 3

Cost Elements of Options 1, 2, and 3: The cost elements for these options would include: facility modifications and operating expenses for the production of plutonium-238 at REDC, FDPF, or FMEF. ATR at INEEL would receive and irradiate shipments of neptunium-237 targets and would require no facility modifications. Plutonium-238 would be separated as a product from the processing operations at a nominal rate of 5 kilograms (11 pounds) per year and shipped to LANL.

Modification Expenses—Irradiation and Plutonium-238 Processing Facilities

REDC—Modification costs at REDC necessary to store neptunium-237 received from SRS, fabricate neptunium-237 targets, and then chemically process irradiated targets were estimated at $39.9 million ($41.1 million in FY 2000 dollars) (Wham 1999b), including contingencies.

FDPF—The costs for facility modifications at FDPF, including the costs for safety documentation, equipment fabrication, and vendor-supplied target fabrication equipment, were estimated at $25.8 million (Folker 1999). This figure includes a 31.5 percent general and accounting (overhead) charge added to the equipment costs, and a 30 percent contingency factor applied to all of the capital cost components. Minor modifications to the existing storage facility at CPP-651, located a short distance from FDPF, were assumed to cost an additional $0.6 million (Folker 1999), for a total cost for facility modifications of $26.4 million ($27.2 million in FY 2000 dollars).

Table 2–6 Summary of Estimated Costs for Alternative 2 (Millions of FY 2000 Dollars)

Cost Elements	*Alternative 2: Use Only Existing Operational Facilities*								
	ATR			***CLWR***			***ATR and HFIR***		
Irradiation Facilities									
FFTF in standby mode (annual) (A)									
FFTF deactivation (B)	281.2			281.2			281.2		
Startup, target development, testing, and evaluation (C)	2			20			3.5		
Irradiation service charge (annual)(D)	8.1			5.1			8.1		
Russian Plutonium-238									
Purchase 5 kilograms (11 pounds) of Russian Plutonium-238 (annual)									
Transport Russian Plutonium-238 to LANL (annual)									
Total Annual Costs (E)									
Processing Facility Alternative Options	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Neptunium-237 Storage and Plutonium-238 Processing Facilities	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**
Modifications	41.2	27.2	62.8	45.1	31.2	62.8	41.2	27.2	62.8
Startup	10	10	10	10	10	10	10	10	10
Subtotal modification and startup costs (F)	**51.2**	**37.2**	**72.8**	**55.1**	**41.2**	**72.8**	**51.2**	**37.2**	**72.8**
Operations (annual) (G)	7.8	6.7	15.3	10.8	9.7	18.3	7.8	6.7	15.3
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities[a]									
Modifications									
Startup									
Subtotal modification and startup costs									
Operations (annual)									
Combined Estimated Costs									
Total Costs (B+C+F)	334.4	320.4	356	356.3	342.4	374	335.9	321.9	357.5
Annual Costs (A+D+E+G)	15.9	14.8	23.4	15.9	14.8	23.4	15.9	14.8	23.4
Plutonium-238 Production Transportation									
Neptunium-237 from SRS (total)	1.4	7.1	8.5	1.4	7.1	8.5	1.4	7.1	8.5
Neptunium-237 targets to irradiation (annual)	0.13	0.08	0.09	0.14	0.16	0.17	0.11	0.10	0.11
Irradiated targets to processing (annual)	0.13	0.08	0.09	0.14	0.16	0.17	0.11	0.10	0.11
Plutonium-238 to LANL (annual)	0.12	0.09	0.13	0.12	0.09	0.13	0.12	0.09	0.13
Total Annual Plutonium-238 Production Shipping and Handling Costs	0.39	0.24	0.32	0.41	0.40	0.46	0.34	0.29	0.35
Medical and Industrial Isotope Transportation (annual) [a]									

a. DOE would continue its medical and industrial isotope production and nuclear research and development activities at the current operating levels of existing facilities.

Note: Shaded areas indicate that no costs would be incurred under that alternative cost element.

FMEF—As previously noted, cost estimates for facility modifications for the production of plutonium-238 at FMEF were based on a production strategy document prepared for DOE (Hoyt et al. 1999), which references an earlier conceptual design report that described a 30-kilogram (66-pound) per year plutonium-238 production facility (WHC/KEHC 1990). In the production strategy document (Hoyt et al. 1999), the $77 million capital cost for FMEF estimated in the conceptual design report was scaled down to $32 million for the required throughput of 5 kilograms (11 pounds) of plutonium-238 per year, using the "six-tenths power rule" (Peters and Timmerhaus 1991). A final capital cost of $45.5 million in current-year dollars was estimated for FMEF facility modifications. By including the additional $16.7 million cost for neptunium-237 storage modifications (see costs for the No Action Alternative, Option 4), the total cost of modifications at FMEF was estimated at

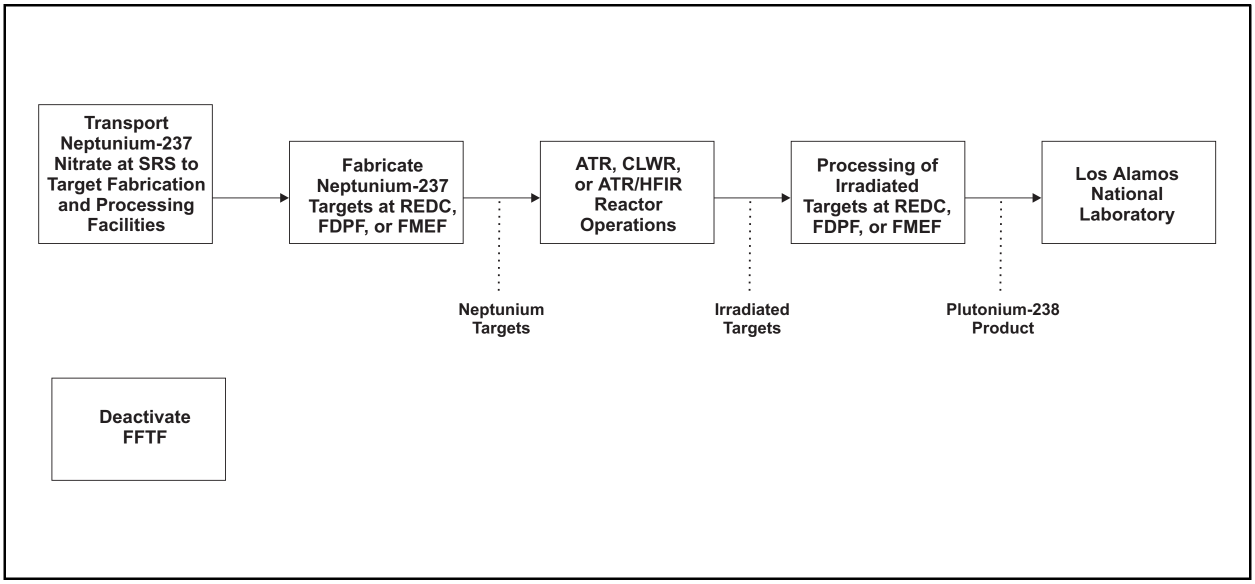

Figure 2–3 Process Flow for Alternative 2 – Use Only Existing Operational Facilities

$62.8 million in FY 2000 dollars. As the flow sheet in the *Summary of Strategy for Implementing Plutonium-238 Production Activities in FMEF* (Hoyt et al. 1999) provided for the fabrication of stainless steel-clad neptunium targets, no additional facility modification charges were made for this purpose.

Operating Expenses—Irradiation and Plutonium-238 Processing Facilities

Operating expenses would be incurred by irradiation services charges and target development, testing, and evaluation at ATR and the associated target fabrication and processing facilities. In addition, costs associated with the inter- and intrasite transportation of materials also were included. Transportation costs would end with delivery to LANL.

ATR—Without specific information on charges for irradiation services at ATR, the estimated cost of $3.15 million per year for irradiation services at HFIR (Wham 1999b) was increased by a ratio of 5/2; i.e., the ratio of the respective production capabilities of ATR and HFIR under the two reactor production alternatives. The irradiation services charge for the production of 5 kilograms (11 pounds) of plutonium-238 per year at ATR was estimated at 5/2 of $3.15 million per year, or $7.88 million per year ($8.05 million per year in FY 2000 dollars). In addition, a target development, testing, and evaluation expense of $2 million ($2.04 in FY 2000 dollars) would be added to the ATR operating costs (Wham 1999c).

REDC—Annual operating costs for target fabrication and chemical processing at REDC were estimated to be $10.8 million per year from FY 2005 through FY 2024 and $12.8 million per year from FY 2025 through FY 2040, in year 2000 dollars (Wham 2000). An additional operating expense of $10 million was added in the first year of operations in FY 2005 for startup costs (Wham 1999c), for a total of $21.0 million in FY 2000 dollars.

FDPF—Annual operating costs at FDPF were estimated on the basis of processing 27 target batches per year, totaling $6.58 million per year ($6.7 million per year in FY 2000 dollars), including a 30 percent contingency (Folker 1999). An additional operating expense of $10 million was added in the first year of operations in FY 2005 for startup costs, consistent with the startup costs at REDC, for a total of $16.6 million ($16.9 million in FY 2000 dollars).

FMEF—Annual operating costs at FMEF were estimated to be the same as those estimated for REDC, i.e., about $10 million per year (Hoyt et al. 1999). An additional $5 million per year was added for facility operations and maintenance support costs, resulting in a total facility operating expense of $15 million per year ($15.3 million per year in FY 2000 dollars). An additional operating expense of $10 million would be added in the first year of operations for startup costs, consistent with the startup costs at REDC, for a total of $28.5 million in FY 2000 dollars.

Transportation Expenses for Options 1, 2, and 3

In addition to the costs of transporting neptunium-237 from SRS to REDC, FDPF, or FMEF for storage (as described for the No Action Alternative, Options 2, 3, and 4), Options 1, 2, and 3 also would incur the transportation expenses of shipping neptunium-237 targets to ATR, as well as return shipments of irradiated targets to REDC, FDPF, or FMEF for chemical processing. Costs per shipment between target fabrication and irradiation facilities were estimated on a cost-per-mile basis for commercial truck transport. Costs per shipment for neptunium-237 from SRS and plutonium-238 to LANL were developed by the Transportation Safeguards Division, DOR Albuquerque Operations Office (Clark 2000).

The total and annual transportation costs in FY 2000 dollars associated with the production of plutonium-238 for Options 1, 2, and 3 involving target irradiation in ATR are presented in **Table 2–7**.

2.3.2 Options 4, 5, and 6

Cost Elements of Options 4, 5, and 6: The cost elements for these options would include: facility modifications and operating expenses for the production of plutonium-238 at REDC, FDPF, or FMEF. A CLWR would receive and irradiate shipments of neptunium-237 targets and would require no facility modifications. Plutonium-238 would be separated as a product from the processing operations at a nominal rate of 5 kilograms (11 pounds) per year and shipped to LANL.

Modification Expenses—Irradiation and Plutonium-238 Processing Facilities

The costs of modifying either REDC, FDPF, or FMEF to fabricate neptunium-237 targets and chemically process irradiated targets to produce plutonium-238 would be the same as described in Alternative 1 (Section 2.2). As in the case of FFTF, the CLWR would require stainless steel-clad neptunium targets, and as noted in Section 2.2, a modification cost increment would also be necessary for REDC and FDPF in the fabrication of neptunium targets for this reactor. No modification costs would be considered necessary at the CLWR.

Operating Expenses—Irradiation and Plutonium-238 Processing Facilities

Annual operating costs associated with the fabrication of neptunium-237 targets and chemically processing irradiated targets to produce plutonium-238 at either REDC, FDPF, or FMEF are described in Alternative 1 (Section 2.2). As in the case of FFTF, the CLWR would require stainless steel-clad neptunium targets, and as noted in Section 2.2, an operating cost increment would also be necessary for all three processing sites (REDC, FDPF and FMEF) for fabrication of neptunium targets for this reactor. Neptunium target development costs were charged to the operating costs of each reactor.

CLWR—Based on review of available data on CLWR irradiation service costs (Sullivan 1999), the cost for CLWR irradiation services to produce plutonium-238 was assumed to be $5 million per year ($5.11 million in FY 2000 dollars). An additional estimated cost of $20 million ($20.4 in FY 2000 dollars) for target development, testing, and evaluation was assumed to be added to the CLWR operating costs (Sullivan 1999).

Table 2-7 Plutonium-238 Production Transportation Costs for Alternative 2 (All Options)

Transportation Elements	*Cost Basis*	*Cost per Shipment (millions)*	*Number of Shipments*	*Total in FY 2000 Dollars (millions)*
Option 1				
Neptunium-237 to REDC	Three SST/SGTs	0.041	33	1.4
Annual Transportation Costs				
REDC neptunium-237 targets to ATR	Commercial truck	0.015	9	0.13
ATR-irradiated neptunium-237 targets to REDC	Commercial truck	0.015	9	0.13
REDC-separated plutonium-238 to LANL	Two SST/SGTs	0.124	1	0.12
Total annual transportation costs in FY 2000 dollars				0.39
Option 2				
Neptunium-237 to FDPF	Three SST/SGTs	0.214	33	7.1
Annual Transportation Costs				
FDPF neptunium-237 targets to ATR	Onsite transport/handling	0.0085	9	0.08
ATR-irradiated neptunium-237 targets to FDPF	Onsite transport/handling	0.0085	9	0.08
FDPF-separated plutonium-238 to LANL	Two SST/SGTs	0.091	1	0.09
Total annual transportation costs in FY 2000 dollars				0.24
Option 3				
Neptunium-237 to FMEF	Three SST/SGTs	0.259	33	8.5
Annual Transportation Costs				
FMEF neptunium-237 targets to ATR	Commercial truck	0.010	9	0.09
ATR-irradiated neptunium-237 targets to FMEF	Commercial truck	0.010	9	0.09
FMEF-separated plutonium-238 to LANL	Two SST/SGTs	0.129	1	0.13
Total annual transportation costs in FY 2000 dollars				0.32
Option 4				
Neptunium-237 to REDC	Three SST/SGTs	0.041	33	1.4
Annual Transportation Costs				
REDC neptunium-237 targets to CLWR	Commercial truck	0.016	9	0.14
CLWR-irradiated neptunium-237 targets to REDC	Commercial truck	0.016	9	0.14
REDC-separated plutonium-238 to LANL	Two SST/SGTs	0.124	1	0.12
Total annual transportation costs in FY 2000 dollars				0.41
Option 5				
Neptunium-237 to FDPF	Three SST/SGTs	0.214	33	7.1
Annual Transportation Costs				
FDPF neptunium-237 targets to CLWR	Commercial truck	0.017	9	0.16
CLWR-irradiated neptunium-237 targets to FDPF	Commercial truck	0.017	9	0.16
FDPF-separated plutonium-238 to LANL	Two SST/SGTs	0.091	1	0.09
Total annual transportation costs in FY 2000 dollars				0.40
Option 6				
Neptunium-237 to FMEF	Three SST/SGTs	0.259	33	8.5
Annual Transportation Costs				
FMEF neptunium-237 targets to CLWR	Commercial truck	0.019	9	0.17
CLWR-irradiated neptunium-237 targets to FMEF	Commercial truck	0.019	9	0.17
FMEF-separated plutonium-238 to LANL	Two SST/SGTs	0.129	1	0.13
Total annual transportation costs in FY 2000 dollars				0.46

Transportation Elements	***Cost Basis***	***Cost per Shipment (millions)***	***Number of Shipments***	***Total in FY 2000 Dollars (millions)***
	Option 7			
Neptunium-237 to REDC	Three SST/SGTs	0.041	33	1.4
Annual Transportation Costs				
REDC neptunium-237 targets to ATR	Commercial truck	0.015	5	0.08
REDC neptunium-237 targets to HFIR	Onsite transport/handling	0.0085	4	0.03
ATR-irradiated neptunium-237 targets to REDC	Commercial truck	0.015	5	0.08
HFIR-irradiated neptunium-237 targets to REDC	Onsite transport/handling	0.0085	4	0.03
REDC-separated plutonium-238 to LANL	Two SST/SGTs	0.124	1	0.12
Total annual transportation costs in FY 2000 dollars				0.34
	Option 8			
Neptunium-237 to FDPF	Three SST/SGTs	0.214	33	7.1
Annual Transportation Costs				
FDPF neptunium-237 targets to ATR	Onsite transport/handling	0.0085	5	0.05
FDPF neptunium-237 targets to HFIR	Commercial truck	0.015	4	0.05
ATR-irradiated neptunium-237 targets to FDPF	Onsite transport/handling	0.0085	5	0.05
HFIR-irradiated neptunium-237 targets to FDPF	Commercial truck	0.015	4	0.05
FDPF-separated plutonium-238 to LANL	Two SST/SGTs	0.091	1	0.09
Total annual transportation costs in FY 2000 dollars				0.29
	Option 9			
Neptunium-237 to FMEF	Three SST/SGTs	0.259	33	8.5
Annual Transportation Costs				
FMEF neptunium-237 targets to ATR	Commercial truck	0.010	5	0.06
FMEF neptunium-237 targets to HFIR	Commercial truck	0.016	4	0.06
ATR-irradiated neptunium-237 targets to FMEF	Commercial truck	0.010	5	0.06
HFIR-irradiated neptunium-237 targets to FMEF	Commercial truck	0.016	4	0.06
FMEF-separated plutonium-238 to LANL	Two SST/SGTs	0.129	1	0.13
Total annual transportation costs in FY 2000 dollars				0.36

Source: Clark 2000.

Transportation Expenses for Options 4, 5, and 6

In addition to the costs of transporting neptunium-237 from SRS to REDC, FDPF, or FMEF for storage (as described for the No Action Alternative, Options 2, 3, and 4), Options 4, 5, and 6 also would incur the transportation expenses of shipping neptunium-237 targets to the CLWR, as well as return shipments of irradiated targets to REDC, FDPF, or FMEF for chemical processing. Costs per shipment between target fabrication and irradiation facilities were estimated on a cost-per-mile basis for commercial truck transport. Costs per shipment for neptunium-237 from SRS and plutonium-238 to LANL were developed by the Transportation Safeguards Division, DOR Albuquerque Operations Office (Clark 2000).

The total and annual transportation costs in FY 2000 dollars associated with the production of plutonium-238 for Options 4, 5, and 6 involving target irradiation in a CLWR are presented in Table 2–7.

2.3.3 Options 7, 8, and 9

Cost Elements of Options 7, 8, and 9: Under these options, neptunium-237 would be shipped to REDC, FDPF, or FMEF for target fabrication and processing. However, these facilities would fabricate and ship neptunium-237 targets to two reactors for irradiation. The two reactors proposed for target irradiation under these options are (1) ATR at INEEL, and (2) HFIR at ORNL. After irradiation, the targets would be shipped back to REDC, FDPF, or FMEF for chemical processing to recover the plutonium-238 product and recycle unconverted neptunium-237. ATR may produce 2 to 5 kilograms (4 to 11 pounds) of plutonium-238 per year, while HFIR may provide from 1 to 2 kilograms (2 to 4 pounds) per year (ORNL 1999). The combined production of the two reactors would amount to 5 kilograms (11 pounds) per year. As in the other options, no modification costs were considered necessary at either ATR or a HFIR. Neptunium-237 target development costs were charged to the operating costs of each reactor.

Modification Expenses—Irradiation and Plutonium-238 Processing Facilities

Facility modifications and operating costs at REDC, FDPF, and FMEF and the cost of transporting neptunium-237 from SRS to one of these facilities for plutonium-238 production would be the same as those described in Options 1, 2, and 3 (Section 2.3.1). Stainless steel target fabrication costs do not apply to these options, because both ATR and HFIR would irradiate aluminum-clad neptunium-237 targets fabricated by one of the three target fabrication and processing facilities. The costs for this type of target fabrication were included in the original estimates for REDC, FDPF, and FMEF.

Operating Expenses—Irradiation and Plutonium-238 Processing Facilities

Facility operating costs at REDC, FDPF, and FMEF and the cost of transporting neptunium-237 from SRS to these facilities would be the same as described for Options 1, 2, and 3 (Section 2.3.1).

ATR—As previously stated, without specific information on charges for irradiation services at ATR, the estimated cost of $3.15 million per year for irradiation services at HFIR (Wham 1999c) was determined by a ratio of 3/2; i.e., the ratio of the respective production capabilities of ATR and HFIR under these options (see Basis of Options 7, 8, and 9). The irradiation services charge for the production of 3 kilograms (7 pounds) of plutonium-238 per year at ATR was estimated at 3/2 of $3.15 million per year, or $4.72 million per year ($4.8 million per year in FY 2000 dollars). In addition, a target development and testing expense of $2 million, or $2.04 million in FY 2000 dollars, was added to ATR operating costs in FY 2005 (Wham 1999c).

HFIR—Annual operating costs for irradiation services at HFIR were estimated at $3.15 million per year (Wham 1999c), or $3.2 million per year in FY 2000 dollars. In addition, a target development and testing expense of $1.5 million, or $1.53 million in FY 2000 dollars, was added to the HFIR operating costs in FY 2005 (Wham 1999c).

Transportation Expenses for Options 7, 8, and 9

Costs for transporting neptunium-237 oxide from SRS to REDC, FDPF, or FMEF and neptunium-237 targets to and from ATR would be the same as described for Options 1 through 3. Costs per shipment for neptunium-237 from SRS to target fabrication and processing facilities and plutonium-238 to LANL were developed by the Transportation Safeguards Division, DOE Albuquerque Operations Office (Clark 2000). The total and annual transportation costs in FY 2000 dollars associated with plutonium-238 production for Options 7, 8, and 9 involving target irradiation in both ATR and HFIR are presented in Table 2–7.

2.4 ALTERNATIVE 3—CONSTRUCT NEW ACCELERATOR(S) (THREE OPTIONS)

Under Alternative 3, DOE would construct and operate two new accelerators at generic sites for separate missions: (1) a high-energy accelerator, generating a neutron flux for the irradiation of neptunium-237 targets to produce plutonium-238; and (2) a low-energy accelerator, to produce medical and industrial isotopes. The missions of both accelerator facilities would include nuclear research and development as well as radioisotope production. In addition, a new processing support facility could be constructed to fabricate and process medical and industrial isotope targets. This facility also would provide laboratory space for DOE's nuclear research and development mission. Costs of constructing and operating each of these facilities under this alternative were evaluated.

Target fabrication and processing for plutonium-238 production define the options presented by Alternative 3, and would take place in either REDC, FDPF, or FMEF, as previously described under Alternative 2 for Options 1, 2, and 3, (Section 2.3.1). Material flows and process operations for Alternative 3 are schematically depicted in **Figure 2–4**.

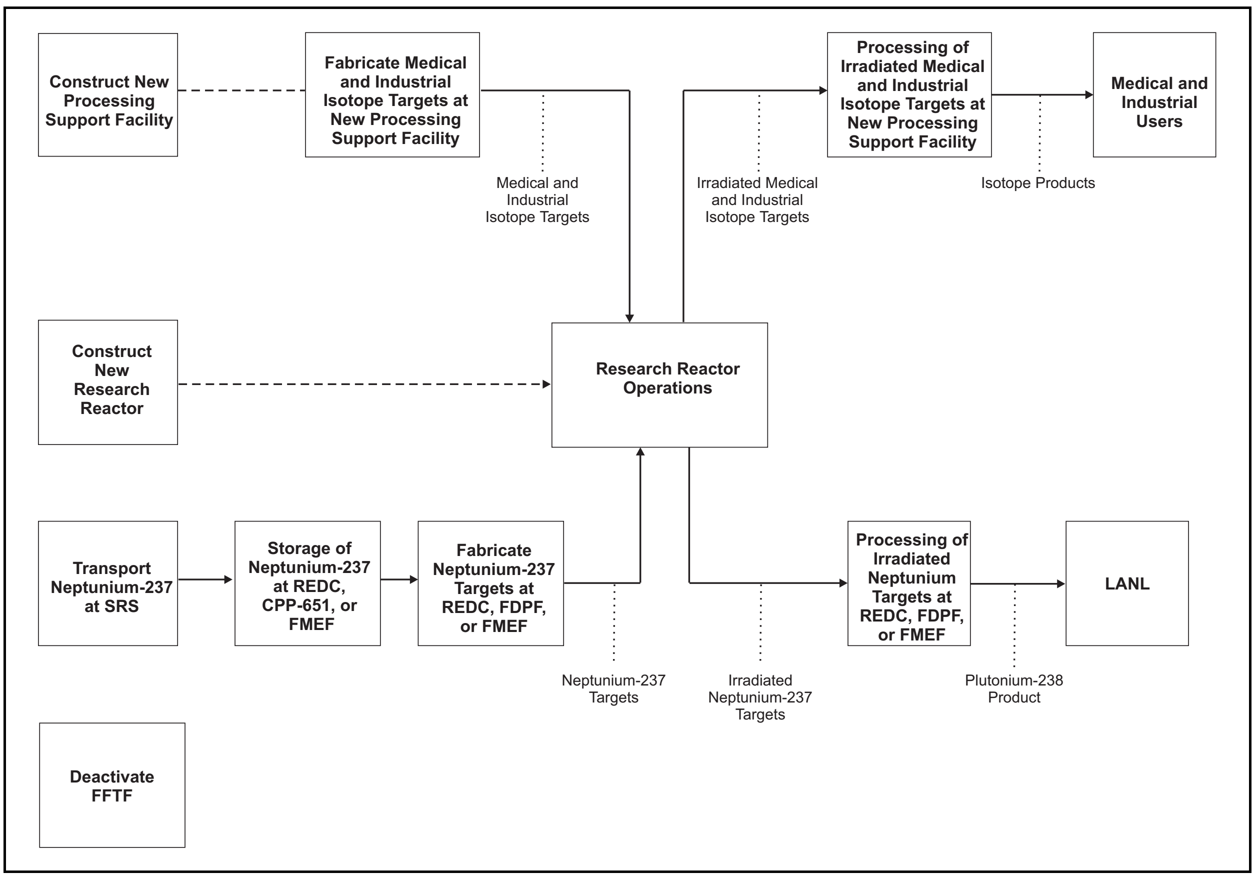

Figure 2–4 Process Flow for Alternative 3 – Construct New Accelerator(s)

Cost Elements: The costs for this alternative would include the construction, startup, and operation of new high- and low-energy accelerators and a new processing support facility that would house the medical and industrial isotope processing. The new accelerator processing support facility would also provide laboratory support to the nuclear research and development mission. Facility modifications and operations at REDC, FDPF, and FMEF and transportation associated with plutonium-238 production and shipment of medical and industrial isotopes would comprise the balance of the Alternative 3 costs. REDC, FDPF, and FMEF would support the high-energy accelerator in plutonium-238 production under these options, respectively. The cost for deactivating FFTF was assumed to be the same as described in Alternative 2 (Section 2.3). A summary of the estimated costs associated with Alternative 3 is presented in **Table 2–8.**

Table 2–8 Summary of Estimated Costs for Alternative 3 (Millions of FY 2000 Dollars)

Cost Elements	*Alternative 3: Construct New Accelerators*			
Irradiation Facilities	High-energy accelerator			1,000.8
	Low-energy accelerator			34.4
Modification or construction	Total			1,035.2
	High-energy accelerator			60
	Low-energy accelerator			0.79
Startup	Total			60.79
	High-energy accelerator			1,060.8
	Low-energy accelerator			35.2
Subtotal Modification or Construction, and Startup Including Target Development, Testing, and Evaluation	**Total**			**1,096.0**
FFTF deactivation				281.2
Total Irradiation Facility Costs (A)				**1,377.2**
Annual Operating Costs	High-energy accelerator			40.6
	Low-energy accelerator			4.5
Operations (annual) (B)	Total			45.1
Processing Facility Alternative Options		**1**	**2**	**3**
Plutonium-238 Processing Facilities		**REDC**	**FDPF**	**FMEF**
Modifications or construction		41.2	27.2	62.8
Startup		10	10	10
Subtotal modification and startup costs (C)		**51.2**	**37.2**	**72.8**
Operations (annual) (D)		7.8	6.7	15.3
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities	**New Processing Support Facility**			
Modification or construction	59.1			
Startup	12			
Subtotal modification or construction, and startup costs (E)	**71.1**			
Operations (annual) (F)	23.3			
Combined Estimated Costs				
Total costs (A+C+E)		1,499.5	1,485.5	1,521.1
Annual Operating Costs (B+D+F)		76.2	75.1	83.7
Plutonium-238 Production Transportation				
Neptunium-237 from SRS (total)		1.4	7.1	8.5
Neptunium-237 targets to irradiation (annual)		0.71	0.71	0.71
Irradiated targets to processing (annual)		0.71	0.71	0.71
Plutonium-238 to LANL (annual)		0.12	0.09	0.13
Total Annual Plutonium-238 Production Shipping and Handling Costs		**1.54**	**1.50**	**1.54**
Medical and Industrial Isotope Transportation (annual)		0.73	0.73	0.73

Construction and Modification Expenses—Irradiation, Plutonium-238, and Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities

Costs would be incurred from the construction of new high- and low-energy accelerators, and a processing support facility. In addition, REDC, FDPF, and FMEF would require modifications to fabricate and process neptunium-237 targets. Modification costs for these facilities, applied to Options 1, 2, and 3, respectively, are described in Alternative 2 for Options 1, 2, and 3 (Section 2.3.1).

High-Energy Accelerator—The cost of constructing a high-energy linac with the capability to provide neutron irradiation of neptunium-237 targets at a production rate of 5 kilograms (11 pounds) of plutonium-238 per year was estimated to be $742.2 million, including an overall contingency of 26 percent (TechSource 2000). This estimate was obtained by scaling costs to those of a much larger high-energy linac, designed to produce tritium (LANL 1997).

The contingencies used in the TechSource estimate are similar to those developed by LANL in 1997 for the tritium linac, as are the overall system contingencies (28 percent in the case of the LANL estimate, 26 percent in the TechSource estimate). A component-by-component analysis of technological risks was performed by LANL to support the cost estimate for the tritium linac (LANL 1997), and recent advances in the technical base for high-energy accelerators, together with the demonstration of LANL's low-energy demonstration accelerator (LEDA) (see Appendix A), have lent confidence in the view that these risks may be relatively low.

However, as discussed in Appendix A, the contingencies proposed by TechSource may be considerably understated for two of the system components. The major area of cost uncertainty is the performance of the high-energy linac target/blanket system, in terms of efficiency of neutron production in the uranium spallation target and efficiency in usage of neutrons in the conversion of neptunium-237 to plutonium-238 in the blanket. In addition, there are large uncertainties in the cost of the TechSource linac target/blanket systems, since they differ substantially from the system designed by LANL, due to the use of uranium as the spallation target rather than tungsten, which is used in the LANL tritium linac design, and to higher deposition density. Although both LANL and TechSource use a 40 percent contingency for target/blanket systems, a 300 percent contingency was assumed for those components in this Cost Report. The second major area of uncertainty is the high-energy linac system itself. The tritium linac system is considered by LANL to be at an intermediate level of technological maturity, and of moderate technical, cost, and schedule risk, and well-demonstrated for electron accelerators (LANL 1997). However, "beta cavities" for protons (which bunch and accelerate a proton beam to an energy suitable for the next accelerating structure) have not yet been demonstrated. Although LANL used a 28 percent contingency for their high-energy tritium linac construction costs and TechSource used 26 percent for their design, a 100 percent contingency was assumed for the plutonium-238 production linac system in this Cost Report. The changes in the contingencies for the two system components discussed above result in a total construction cost of $1 billion for the plutonium-238 linac system; this cost was entered in Table 2–8.

Low-Energy Accelerator—The cost of constructing a low-energy cyclotron, capable of producing a range of medical and industrial radioisotopes by proton interactions with targets, was estimated to be $34.4 million, including a 20 percent contingency (see Table 2–8). The costs of constructing new high- and low-energy accelerators are discussed in Appendix A.

New Processing Support Facility—The cost of a new facility to support the low-energy accelerator and medical and industrial isotope production and nuclear research and development missions was estimated to be $59.1 million (SAIC 2000a) (see Table 2–8). New processing support facility construction costs are discussed in Appendix C.

Operating Expenses—Irradiation, Plutonium-238, and Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities

Annual operating expenses for the facilities under Alternative 3 would include startup and operating costs.

Startup and operating costs for the three existing DOE facilities (REDC, FDPF, and FMEF) that would provide neptunium-237 target fabrication and processing support for the high-energy accelerator in plutonium-238 production are described under Alternative 2 for Options 1, 2, and 3 (Section 2.3.1). These facilities would begin operations upon receipt of neptunium-237 from SRS.

High-Energy Accelerator—Startup and operating costs for a new high-energy accelerator designed to generate neutrons to irradiate neptunium-237 targets and produce 5 kilograms (11 pounds) of plutonium-238 per year were estimated to be $60 and about 40.6 million annually, respectively (TechSource 2000). Several components of this total cost were also scaled from costs developed from the LANL tritium linac (LANL 1997).

Low-Energy Accelerator—Startup and operating costs of the low-energy accelerator were estimated to be $0.79 and 4.5 million annually, respectively, including accelerator core operations, nuclear research and development, and production. The bases for estimating the operating costs at both accelerators are discussed in Appendix A.

New Processing Support Facility—Startup and operating costs for a new medical and industrial isotope production processing support facility were estimated to be $12 and approximately 23.3 million annually, respectively (SAIC 2000a). This estimate is considerably higher than the respective $12.1 and 12.9 million annual operating costs estimated for medical and industrial isotope production at RPL/306–E and FMEF (Nielsen 2000). The difference was attributed to the cost of operating a new stand-alone facility, compared to cost sharing at an existing facility.

Transportation Expenses for Alternative 3

Costs for transportation between facilities involved in plutonium-238 production would include a total of 33 shipments of neptunium-237 from SRS to REDC, FDPF, or FMEF (Options 1, 2, and 3, respectively) for neptunium-237 target fabrication. Annual shipments include: (1) 3 shipments of neptunium-237 targets from REDC, FDPF, or FMEF to a new high-energy accelerator for irradiation services; (2) 3 return shipments of irradiated neptunium-237 targets to REDC, FDPF, or FMEF for the recovery of the plutonium-238; and (3) 1 shipment of the plutonium-238 product from REDC, FDPF, or FMEF to LANL. Transportation costs include costs for security (Clark 2000).

Costs for transportation between facilities involved in medical and industrial isotope production would include: intrasite transportation of targets fabricated in a new processing support facility to the new low-energy accelerator; intrasite transportation of irradiated targets from the low-energy accelerator to a new processing support facility; and offsite transportation of separated and packaged isotopes from a new processing support facility to the nearest major air freight terminal. Annual transportation costs for these transfers were assumed to be the same as described for Alternative 1 (Section 2.2) and were estimated to be $0.67 million in FY 1996 dollars and $0.73 million in FY 2000 dollars (PNNL 1997).

Transportation costs for plutonium-238 production for Alternative 3 are presented in **Table 2–9**.

Table 2-9 Plutonium-238 Production Transportation Costs for Alternative 3 (All Options)

Transportation Elements	*Cost Basis*	*Cost per Shipment (millions)*	*Number of Shipments*	*Total in FY 2000 Dollars (millions)*
Option 1				
Neptunium-237 to REDC	Three SST/SGTs	0.041	33	1.4
Annual Transportation Costs				
REDC neptunium-237 targets to accelerator	One SST/SGT	0.236	3	0.71
Accelerator-irradiated neptunium-237 targets to REDC	One SST/SGT	0.236	3	0.71
REDC-separated plutonium-238 to LANL	Two SST/SGTS	0.124	1	0.12
Total annual transportation costs in FY 2000 dollars				1.54
Option 2				
Neptunium-237 to FDPF	Three SST/SGTs	0.214	33	7.1
Annual Transportation Costs				
FDPF neptunium-237 targets to accelerator	One SST/SGT	0.236	3	0.71
Accelerator-irradiated neptunium-237 targets to FDPF	One SST/SGT	0.236	3	0.71
FDPF-separated plutonium-238 to LANL	Two SST/SGTs	0.091	1	0.09
Total annual transportation costs in FY 2000 dollars				1.50
Option 3				
Neptunium-237 to FMEF	Three SST/SGTs	0.259	33	8.5
Annual Transportation Costs				
FMEF neptunium-237 targets to accelerator	One SST/SGT	0.236	3	0.71
Accelerator-irradiated neptunium-237 targets to FMEF	One SST/SGT	0.236	3	0.71
FMEF-separated plutonium-238 to LANL	Two SST/SGTs	0.129	1	0.13
Total annual transportation costs in FY 2000 dollars				1.54

Source: Clark 2000.

2.5 ALTERNATIVE 4—CONSTRUCT NEW RESEARCH REACTOR (THREE OPTIONS)

Under Alternative 4, DOE would construct and operate a new research reactor designed to produce medical and industrial isotopes and plutonium-238, and to support the nuclear research and development mission, and FFTF would be permanently deactivated. In addition, a new processing support facility could be constructed to fabricate and process medical and industrial isotope targets. This facility would also provide laboratory space for DOE's nuclear research and development mission.

Target fabrication and processing for plutonium-238 production define the options presented under Alternative 4. These activities would take place in one of three existing DOE facilities REDC (Option 1), FDPF (Option 2), and FMEF (Option 3), described previously under Alternative 2 for Options 1, 2, and 3 (Section 2.3.1). Material flows and process operations for Alternative 4 are schematically depicted in **Figure 2–5**.

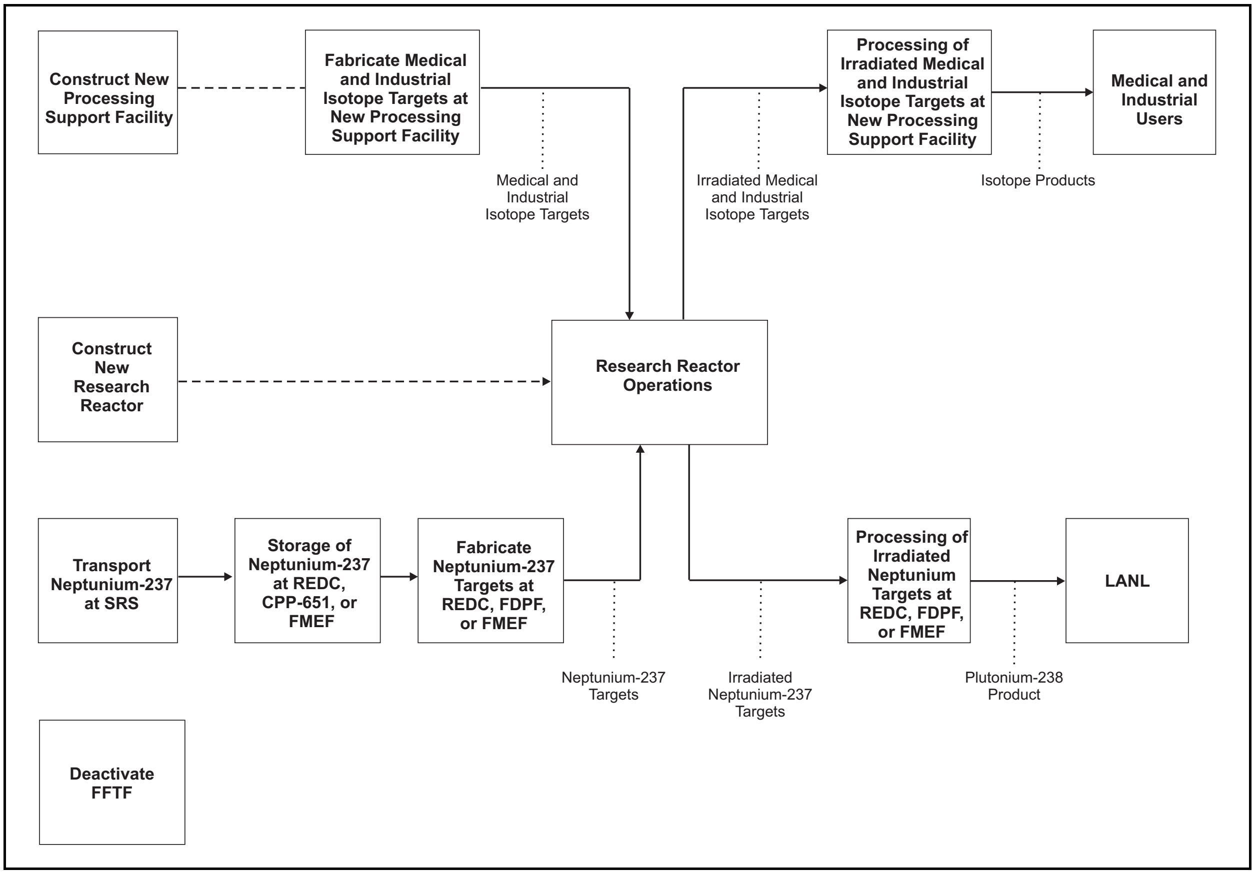

Figure 2–5 Process Flow for Alternative 4 – Construct New Research Reactor

Cost Elements: The costs for this alternative would include the construction and operation of a new research reactor and a new processing support facility. Facility modifications and operations at REDC, FDPF, or FMEF and transportation associated with plutonium-238 and medical and industrial isotope production comprise the balance of the Alternative 4 costs. REDC, FDPF, or FMEF would support the new research reactor in plutonium-238 production under these options, respectively. The cost for deactivating FFTF was assumed to be the same as described in Alternative 2 (Section 2.3). A summary of the estimated costs associated with Alternative 4 is presented in **Table 2–10.**

Construction and Modification Expenses—Irradiation, Plutonium-238, and Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities

Costs would be incurred from the construction of a new research reactor and a new processing support facility. In addition, REDC, FDPF, or FMEF would require modifications to fabricate and process neptunium-237 targets to produce plutonium-238. Modification costs for REDC, FDPF, and FMEF are presented in Alternative 2 for Options 1, 2, and 3 (Section 2.3.1).

New Research Reactor—The cost of constructing a new 50-megawatt research reactor was estimated to be $287 million (SAIC 2000b). The basis for this estimate is presented in Appendix B of this Cost Report. As discussed in Appendix B, this estimate includes a 50 percent contingency, since it was based on a preconceptual design. This estimate was evaluated and deemed reasonable on the basis of comparison to construction costs for other existing and planned research reactors. This evaluation is also presented in Appendix B.

Table 2–10 Summary of Estimated Costs for Alternative 4 (Millions of FY 2000 Dollars)

Cost Elements	*Alternative 4: Construct New Research Reactor*		
Irradiation Facilities			
Modification or construction	287		
Startup	25		
Subtotal Modification or Construction, and Startup Including Target Development, Testing, and Evaluation	**312**		
FFTF deactivation	281.2		
Total Irradiation Facility Costs (A)	**593.2**		
Annual Operating Costs			
Operations (annual) (B)	25		
Processing Facility Alternative Options	**1**	**2**	**3**
Plutonium-238 Processing Facilities	**REDC**	**FDPF**	**FMEF**
Modifications or construction	41.2	27.2	62.8
Startup	10	10	10
Subtotal modification and startup costs (C)	**51.2**	**37.2**	**72.8**
Operations (annual) (D)	7.8	6.7	15.3
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities	**New Processing Support Facility**		
Modification or construction	59.1		
Startup	12		
Subtotal modification or construction, and startup costs (E)	**71.1**		
Operations (annual) (F)	23.3		
Combined Estimated Costs			
Total Costs (A+C+E)	715.5	701.5	737.1
Annual Operating Costs (B+D+F)	56.1	55	63.6
Plutonium-238 Production Transportation			
Neptunium-237 from SRS (total)	1.4	7.1	8.5
Neptunium-237 targets to irradiation (annual)	2.12	2.12	2.12
Irradiated targets to processing (annual)	0.14	0.16	0.17
Plutonium-238 to LANL (annual)	0.12	0.09	0.13
Total Annual Plutonium-238 Production Shipping and Handling Costs	**2.39**	**2.37**	**2.42**
Medical and Industrial Isotope Transportation (annual)	0.73	0.73	0.73

New Processing Support Facility—The cost of constructing a new processing support facility was estimated to be $59.1 million (SAIC 2000a). The estimate was based on the cost of designing and constructing a 15,850-square-meter (52,000-square-foot) facility, including equipment for target fabrication and processing, and startup and testing costs. Appendix C presents the basis for estimating the cost of constructing a new processing support facility for medical and industrial radioisotope production and nuclear research and development.

Operating Expenses—Irradiation, Plutonium-238, Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities

Facility operating expenses for the three options under Alternative 4 would include startup and operating costs.

Startup and Operating Costs

Startup and operating costs for the three existing DOE facilities (REDC, FDPF, or FMEF) that would provide target fabrication and irradiated target processing support for the new research reactor in plutonium-238 production are described in Alternative 2 for Options 1, 2, and 3 (Section 2.3.1). These facilities would begin operations upon receipt of neptunium-237 from SRS.

New Research Reactor—Startup and annual operating costs for a new 50-megawatt research reactor were both estimated to be $25 million (SAIC 2000b). The bases for these estimates are presented in Appendix B.

New Processing Support Facility—Startup and annual operating costs for a new medical and industrial isotope production processing support facility were estimated to be $12 and 23.3 million, respectively (SAIC 2000a). The operating cost estimate is considerably higher than the $12.1 and 12.9 million annual operating costs estimated for medical and industrial isotope production at RPL/306–E and FMEF, respectively (Nielsen 2000). The difference was attributed to the cost of operating a stand-alone facility, compared to cost sharing at an existing facility.

Transportation Expenses for Alternative 4

Transportation costs between facilities involved in plutonium-238 production would include a total of 33 shipments of neptunium-237 from SRS to REDC, FDPF, or FMEF (Options 1, 2, and 3, respectively) for neptunium-237 target fabrication. Annual shipments include: 9 shipments of neptunium-237 targets from REDC, FDPF, or FMEF to the new research reactor for irradiation services; (2) 9 return shipments of irradiated neptunium-237 targets to REDC, FDPF, or FMEF for plutonium-238 production; and (3) 1 shipment of the plutonium-238 product from REDC, FDPF, or FMEF to LANL. Transportation costs would include costs for security (Clark 2000). Transportation costs for plutonium-238 production for Alternative 4 are presented in **Table 2–11**.

Transportation costs between facilities involved in medical and industrial isotope production would include: intrasite transportation of targets fabricated in a new processing support facility to the new research reactor; intrasite transportation of irradiated targets from the reactor to a new processing support facility; and offsite transportation of separated and packaged isotopes from a new processing support facility to the nearest major air freight terminal. Annual transportation costs for these transfers were assumed to be the same as described for Alternative 1 (Seciton 2.2) and were estimated to be $0.67 million in FY 1996 dollars and $0.73 million in FY 2000 dollars (PNNL 1997), amounting to a total cost of $25.5 million.

2.6 ALTERNATIVE 5—PERMANENTLY DEACTIVATE FFTF

Under Alternative 5, FFTF would be permanently deactivated, as in Alternatives 2, 3, and 4. The cost for deactivating FFTF was assumed to be the same as described in Alternative 2 (Section 2.3).

Table 2–11 Plutonium-238 Production Transportation Costs for Alternative 4 (All Options)

Transportation Elements	*Cost Basis*	*Cost per Shipment (millions)*	*Number of Shipments*	*Total in FY 2000 Dollars (millions)*
Option 1				
Neptunium-237 to REDC	Three SST/SGTs	0.041	33	1.4
Annual Transportation Costs				
REDC neptunium-237 targets to research reactor	One SST/SGT	0.236	9	2.12
Research-reactor-irradiated neptunium-237 targets to REDC	Commercial truck	0.016	9	0.14
REDC-separated plutonium-238 to LANL	Two SST/SGTs	0.124	1	0.12
Total annual transportation costs in FY 2000 dollars				2.39
Option 2				
Neptunium-237 to FDPF	Three SST/SGTs	0.214	33	7.1
Annual Transportation Costs				
FDPF neptunium-237 targets to research reactor	One SST/SGT	0.236	9	2.12
Research-reactor-irradiated neptunium-237 targets to FDPF	Commercial truck	0.017	9	0.16
FDPF-separated plutonium-238 to LANL	Two SST/SGTs	0.091	1	0.09
Total annual transportation costs in FY 2000 dollars				2.37
Option 3				
Neptunium-237 to FMEF	Three SST/SGTs	0.259	33	8.5
Annual Transportation Costs				
FMEF neptunium-237 targets to research reactor	One SST/SGT	0.236	9	2.12
Research-reactor-irradiated neptunium-237 targets to FMEF	Commercial truck	0.019	9	0.17
FMEF-separated plutonium-238 to LANL	Two SST/SGTs	0.129	1	0.13
Total annual transportation costs in FY 2000 dollars				2.42

Source: Clark 2000.

3.0 COST ANALYSES

3.1 OVERALL ASSESSMENT

Estimated costs of nonexpanded infrastructure alternatives (the No Action Alternative and Alternatives 2 and 5) and expanded infrastructure alternatives (Alternatives 1, 3, and 4) identified in Figure S–1 were summarized in Section S.4. In this section, a more detailed analysis of the total capital investments and operating costs of the respective alternatives is made. This detail for the nonexpanded and expanded infrastructure alternatives, respectively is provided in **Tables 3–1** and **3–2**.

Capital costs signify either modifications to facilities or construction involving new plants and equipment. Expenditures for operating costs vary by type of alternative; for example, operating costs for the No Action Alternative pertain to long-term storage, while operating costs for alternatives in which isotopes are produced include expenses such as labor, materials, and overhead.

Several of the alternatives for expanding or replacing DOE's current nuclear infrastructure would involve either the extensive modification of existing plants and equipment, or the construction of new facilities based, in some cases, on the use of new technologies. Cost estimates for each of the alternatives were based on preconceptual designs, and reflect the inaccuracies expected of preconceptual designs, approximation of costs, and contingencies made in advance of detailed designs. It is therefore important to bear in mind these limitations in accuracy of these cost estimates when making comparative judgments between alternatives. As noted in Section 1.4, Cost Methodology and Assumptions, it was assumed that errors in the cost estimates that are based on conceptual or preconceptual designs or approximations such as the "six-tenths power rule" (see Section B.2.1) could be greater than 30 percent (Peters and Timmerhaus 1991). Thus, it is necessary to consider the possible effects of cost variances in Tables 3–1 and 3–2 when comparing options within any given alternative, or in making comparisons among alternatives themselves.

Nonexpanded Infrastructure Alternatives

A summary of the estimated cost of the nonexpanded infrastructure alternatives including the No Action Alternative and Alternatives 2 and 5 is presented in Table 3–1. As previously stated for the expanded infrastructure alternatives, capital costs (costs of modifying existing facilities), annual operating costs, and transportation costs are presented for irradiation facilities and neptunium-237 storage and plutonium-238 processing facilities. In addition, costs for the purchase and transport of Russian plutonium-238 are presented. DOE would continue its medical and industrial isotope production and nuclear research and development activities at the current operating levels of existing facilities.

- Under the No Action Alternative, FFTF would be maintained in its current standby mode at a cost of \$40.8 million per year. The No Action Alternative would also include the annual purchase of 5 kilograms (11 pounds) of Russian plutonium-238 at an assumed annual cost of \$8.84 million per year. Additional costs would depend on which option is chosen under the No Action Alternative. Option 1 would only incur the cost of maintaining FFTF in standby and the purchase of plutonium-238 from Russia. Options 2, 3, or 4 would involve the transport of neptunium-237 from SRS to REDC, CPP-651, or FMEF for long-term storage (costing \$17 to 19 million for storage modifications and startup at REDC and FMEF and \$2 million at CPP-651, which has existing storage capacity). Annual operating costs at all three storage sites would be approximately \$1.5 to 2.6 million per year. The total costs of transporting neptunium-237 from SRS to

Table 3–1 Summary of Estimated Costs of Nonexpanded Infrastructure Alternatives (Millions of FY 2000 Dollars)

Cost Elements	*Alternatives*													
	No Action				*Alternative 2: Use Only Existing Operational Facilities*									*Alternative 5: Deactivate FFTF*
					ATR			*CLWR*			*ATR and HFIR*			
Irradiation Facilities														
FFTF in standby mode (annual) (A)	40.8													
FFTF deactivation (B)					281.2			281.2			281.2			281.2
Startup; target development, testing, and evaluation (C)					2			20			3.5			
Irradiation services charge(annual) (D)					8.1			5.1			8.1			
Russian Plutonium-238														
Purchase 5 kilograms of Russian Plutonium-238 (annual)	8.7 (a)													
Transport Russian Plutonium-238 to LANL (annual)	0.14													
Total Annual Costs (E)	**8.84**													
Processing Facility Alternative Options	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Neptunium-237 Storage and Plutonium-238 Processing Facilities		**REDC**	**CPP-651**	**FMEF**	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**	
Modifications		15.4	0.62	16.7	41.2	27.2	62.8	45.1	31.2	62.8	41.2	27.2	62.8	
Startup		1.5	1.5	2.6	10	10	10	10	10	10	10	10	10	
Subtotal Modification and Startup Costs (F)		**16.9**	**2.12**	**19.3**	**51.2**	**37.2**	**72.8**	**55.1**	**41.2**	**72.8**	**51.2**	**37.2**	**72.8**	
Operations (annual) (G)		1.5	1.5	2.6	7.8	6.7	15.3	10.8	9.7	18.3	7.8	6.7	15.3	
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities[b]														
Modifications														
Startup														
Subtotal Modification and Startup Costs														
Operations (annual)														
Combined Estimated Costs														
Total Costs (B+C+F)	0	16.9	2.12	19.3	334.4	320.4	356	356.3	342.4	374	335.9	321.9	357.5	281.2
Annual Operating Costs (A+D+E+G)	49.6	51.1	51.1	52.2	15.9	14.8	23.4	15.9	14.8	23.4	15.9	14.8	23.4	0
Plutonium-238 Production Transportation														
Neptunium-237 from SRS (total)		1.4	7.1	8.5	1.4	7.1	8.5	1.4	7.1	8.5	1.4	7.1	8.5	
Neptunium-237 targets to irradiation (annual)					0.13	0.08	0.09	0.14	0.16	0.17	0.11	0.10	0.11	
Irradiated targets to processing (annual)					0.13	0.08	0.09	0.14	0.16	0.17	0.11	0.10	0.11	
Plutonium-238 to LANL (annual					0.12	0.09	0.13	0.12	0.09	0.13	0.12	0.09	0.13	
Total Annual Plutonium-238 Production Shipping and Handling Costs					**0.39**	**0.24**	**0.32**	**0.41**	**0.40**	**0.46**	**0.34**	**0.29**	**0.35**	
Medical and Industrial Isotope Transportation (annual)[b]														

a. Based on FY 2000 contract year eight, $1,739 million per kilogram × 5 kilograms. Succeeding year purchase price escalated at a contractual 3.5 percent per year for the remaining two years of the contract.
b. DOE would continue its medical and industrial isotope production and nuclear research and development activities at the current operating levels of existing facilities.
Note: Shaded areas indicate that no costs would be incurred under that alternative and/or option.

Table 3–2 Summary of Estimated Costs of Expanded Infrastructure Alternatives (Millions of FY 2000 Dollars)

Cost Elements	*Alternatives*								
	Alternative 1: Restart FFTF			*Alternative 3: Construct New Accelerator(s)*			*Alternative 4: Construct New Research Reactor*		
Irradiation Facilities Modification or construction	37.7			High-energy acc. 1,000.8 Low-energy acc. 34.4 Total 1,035.2			287		
Startup	276.3			High-energy acc. 60 Low-energy acc. 0.79 Total 60.79			25		
Subtotal Modification or Construction and Startup, Including Target Development, Testing, and Evaluation	**314**			High-energy acc. 1,060.8 Low-energy acc. 35.2 **Total 1,096.0**			**312**		
FFTF deactivation				281.2			281.2		
Total Irradiation Facility Costs (A)	**314**			**1,377.2**			**593.2**		
Annual Operating Costs Operations (annual) (B)	Onsite MOX 56.2 Foreign MOX[a] 56.7 HEU[b] 63.9			High-energy acc. 40.6 Low-energy acc. 4.5 Total 45.1			25		
Processing Facility Alternative Options	**1 and 4[c]**	**2 and 5[c]**	**3 and 6[c]**	**1**	**2**	**3**	**1**	**2**	**3**
Plutonium-238 Processing Facilities	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**	**REDC**	**FDPF**	**FMEF**
Modification or construction Startup	45.1 10	31.2 10	62.8 10	41.2 10	27.2 10	62.8 10	41.2 10	27.2 10	62.8 10
Subtotal Modification and Startup Costs (C)	**55.1**	**41.2**	**72.8**	**51.2**	**37.2**	**72.8**	**51.2**	**37.2**	**72.8**
Operations (annual) (D)	10.8	9.7	18.3	7.8	6.7	15.3	7.8	6.7	15.3
Medical and Industrial Isotope/Nuclear Research and Development Processing Facilities	**RPL/306-E**		**FMEF**	**New Processing Support Facility**			**New Processing Support Facility**		
Modification or construction Startup	29.4[d]		36.8[d]	59.1 12			59.1 12		
Subtotal Modification or Construction, and Startup Costs (E)	**29.4**		**36.8**	**71.1**			**71.1**		
Operations (annual) (F)	12.1		12.9	23.3			23.3		
Combined Estimated Costs Total Costs (A+C+E) Annual Operating Costs[e] (B+D+F)	398.5 81.8	384.6 80.7	423.6 90.1	1,499.5 76.2	1.485.5 75.1	1,521.1 83.7	715.5 56.1	701.5 55	737.1 63.6
Plutonium-238 Production Transportation Neptunium-237 from SRS (total)	1.4	7.1	8.5	1.4	7.1	8.5	1.4	7.1	8.5
Neptunium-237 targets to irradiation (annual)	0.14	0.09	0.08	0.71	0.71	0.71	2.12	2.12	2.12
Irradiated targets to processing (annual)	0.14	0.09	0.08	0.71	0.71	0.71	0.14	0.16	0.17
Plutonium-238 to LANL (annual)	0.12	0.09	0.13	0.12	0.09	0.13	0.12	0.09	0.13
Total Annual Plutonium-238 Production Shipping and Handling Costs	**0.41**	**0.28**	**0.28**	**1.54**	**1.50**	**1.54**	**2.39**	**2.37**	**2.42**
Medical and Industrial Isotope Transportation (annual)	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73

Key: acc. = accelerator.

a. Includes $0.53 million per year for domestic transport of German MOX fuel to FFTF.
b. Includes $1.6 to 1.7 million per year for domestic transport of fabricated HEU fuel to FFTF.
c. Options 1, 2, and 3 assume FFTF would use onsite MOX, German MOX, and then HEU fuel during operations. Options 4, 5, and 6 assume FFTF would use onsite MOX, then HEU fuel during operations.
d. Startup costs included in modification costs per referenced data.
e. Alternative 1 annual operating costs include an average of the FFTF operating costs.

Note: Shaded area indicates that no costs would be incurred under that alternative cost element.

storage facilities is a function of distance and would vary from $1.4 million for transport to REDC to $7.1 to 8.5 million to CPP-651 or FMEF, respectively.

- Alternative 2 would combine the use of existing irradiation facilities (ATR, ATR in combination with HFIR, or a CLWR) with the choice of three processing facilities (REDC, FDPF, or FMEF) to provide nine different options for producing plutonium-238. FFTF would be deactivated under all options, at a cost of $281 million constituting the major cost element of all options under Alternative 2. In addition, the following costs would be incurred:

  - Processing facility modification costs would be about $37 million for FDPF; $51 million for REDC; and $73 million for FMEF (for the addition of most process flowsheet items of equipment, within existing plant and services) for Options 1, 2, 3, 7, 8, and 9. An additional cost of $4 million for additional facility modifications was estimated for REDC and FDPF to fabricate stainless steel targets for the CLWR under Options 4, 5, and 6.

  - Processing facility operating costs would be about $7 to 9 million per year for REDC and FDPF and $15 million per year for FMEF for Options 1, 2, 3, 7, 8, and 9. An additional cost of $3 million was estimated for REDC, FDPF, and FMEF for the fabrication of stainless steel targets for the CLWR under Options 4, 5, and 6.

  - Irradiation charges would be $8 million per year for ATR and ATR in combination with HFIR, and $5 million per year for the CLWR.

  - Total transportation costs for the shipment of neptunium-237 from SRS to processing facilities would be the same as previously described for the enhanced infrastructure alternatives and the No Action Alternative. Differences in annual plutonium-238 production shipping and handling costs between the options are due to distance, the location of the irradiation facility, and the number of shipments. All shipments to and from irradiation facilities under this alternative would be by commercial truck.

- Alternative 5 would involve the deactivation of FFTF, at a cost of $281 million.

Expanded Infrastructure Alternatives

Table 3–2 indicates the following significant aspects of the expanded infrastructure alternative costs:

- With respect to irradiation facilities, which constitute the major cost element of these alternatives, capital costs would be in the order of $300 million for Alternative 1 (FFTF restart) and for Alternative 4 (construction of a new research reactor), and more than $1 billion for Alternative 3 (construction of new accelerators). An additional burden of $281 million would be placed on Alternatives 3 and 4 for FFTF deactivation costs because these alternatives involve the construction of new facilities. Alternative 1, FFTF restart, would not incur this cost.

- The estimated annual costs of operating these irradiation facilities would be: $25 million per year for Alternative 4; $45 million per year for Alternative 3; and $59 to 64 million per year for Alternative 1.

- Costs of other facilities can be categorized by the type of support provided. Facilities that would support the plutonium-238 production mission (by fabricating neptunium targets and processing irradiated targets) include REDC, FDPF, and FMEF (Options 1, 2, and 3, respectively). These facilities would require varying degrees of modification to perform this mission, resulting in investments of $41.2, 27.2, and 62.8 million, for REDC, FDPF, and FMEF, respectively, in Alternatives 3 and 4. The lower end of this range of front-end costs represents investments in REDC and FDPF, which have been built. FMEF has not been fully equipped nor operated, and would therefore require the higher modification costs to bring this facility online. Similarly, operating costs would be $7.8, 6.7, and 15.3 million per year for REDC, FDPF, and FMEF, respectively, in Alternatives 3 and 4, is due to the availability of shared resources that can reduce operating costs, compared to a nonoperating facility like FMEF. An additional cost of $4 million for additional facility modifications at REDC and FDPF and $3 million operating costs at REDC, FDPF, and FMEF was estimated for the fabrication of stainless steel targets for the FFTF under Alternative 1.

- Facilities that support the medical and industrial isotope production and expanded nuclear research and development mission (by fabricating targets and processing irradiated targets to recover, package, and ship the radioisotopes) include: RPL/306–E at Hanford (Alternative 1 Options 1, 2, 4, and 5); FMEF (Alternative 1 Options 3 and 6); and a new processing support facility that would support this mission in Alternatives 3 and 4. Modification costs (including startup) for the Hanford facilities would be $29.4 and 36.8 million (RPL/306–E and FMEF, respectively), and $71.1 million for the construction of a new processing support facility. Annual operating costs would be $12.1 and 12.9 million per year for RPL/306–E and FMEF, which would share services with other ongoing work; and $23.3 million per year for the a new processing support facility.

- Transportation costs for the expanded infrastructure alternatives would be higher for the plutonium-238 production mission than the medical and industrial isotope mission, due to distances traveled, the number of shipments, and the cost of secure shipments. Differences in annual plutonium-238 production shipping and handling costs between the three alternatives are due to the cost of secure transport versus commercial truck and the number of shipments. Under Alternative 1, commercial trucks would be used to transport neptunium targets between processing facilities and FFTF. Alternative 3 would have the fewest number of shipments but requires the use of more expensive secure transport. Alternative 4 would have the same number of shipments and nearly the same shipping and handling costs as Alternative 1, but would require the use of secure transport to ship fabricated neptunium-237 targets from processing facilities to the new research reactor. The difference in the total costs of shipping neptunium-237 from the Savannah River Site (SRS) to plutonium-238 processing facilities is a function of distance from SRS. These costs would range from a low of $1.4 million per year for REDC to about $7 to 8 million per year for FDPF and FMEF. By comparison, transportation costs in medical and industrial isotope production (involving intrasite transfers of relatively small targets and offsite transfers to the nearest air freight terminal) would amount to $0.73 million per year for each alternative.

In summary, the combined estimated cost of all capital costs (for the modification or construction of new facilities, including startup, target development, testing, and evaluation, and FFTF deactivation) in the expanded infrastructure alternatives would range from $385 to 424 million for Alternative 1; from $1,485 to 1,521 million for Alternative 3; and from $702 to 737 million for Alternative 4. Alternative 1 would be dominated by the FFTF startup costs; Alternative 3 would be dominated by the cost of the high-energy accelerator, which would cost $1 billion, in comparison to the low-energy accelerator, which would cost $34 million; and Alternative 4 would be dominated by the cost of constructing a new research reactor, which would be nearly equal the cost of deactivating FFTF.

The combined estimated cost of annual operating costs (exclusive of transportation costs) in the expanded infrastructure alternatives would be $82 to 90 million per year for Alternative 1; $75 to 84 million per year for

Alternative 3; and $55 to 64 million per year for Alternative 4. The operating costs of the irradiation facilities used in these alternatives would comprise a major portion of the total operating cost of these facilities over time, particularly in Alternative 1 (due to FFTF operating costs) and in Alternative 3 (due to the high-energy accelerator operating costs).

3.2 ANALYSES OF REVENUES GENERATED BY THE SALE OF RADIOISOTOPES

Several alternatives evaluated in this Cost Report involve costs associated with the startup of FFTF, the construction of new accelerator facilities, or the construction of a new research reactor for the production of medical and industrial isotopes and plutonium-238 for space missions, and for nuclear research and development. Recent projections of the potential future market for the sale of medical radioisotopes have been made, given the stimuli of the increased availability of these isotopes, medical research indicative of their efficacy, and growing demand (Wagner et al. 1999, Frost & Sullivan 1997, MUSC 1997, PNNL 1997, and PNNL 1999). These projections were evaluated from the aspect of the potential for recovery of Government costs to provide these facilities.

Summary of the Findings of Referenced Studies—An expert panel convened by DOE's Office of Nuclear Energy, Science and Technology (Wagner et al. 1999) expressed its belief that the expected annual growth rate of medical radionuclide usage during the next 20 years will be between 7 to 14 percent for therapeutic applications and 7 to 16 percent for diagnostic applications. These findings are cognizant of two other major studies made in recent years: an *FFTF Medical Isotopes Market Study* (Frost & Sullivan 1997) and a Medical University of South Carolina (MUSC) *Evaluation of Medical Radionuclide Production with the Accelerator Production of Tritium Facility* (MUSC 1997).

Projected Growth Rates for the Therapeutic Radioisotopes Market—The Frost & Sullivan report projected an increase in demand of 14 percent per year for therapeutic radioisotopes and 16 percent per year for diagnostic radioisotopes. Based on more conservative projections by industry and Arthur Anderson and Company, the MUSC report used a 7 to 10 percent per year growth in demand for its projections. The expert panel considered the radioisotope needs over the next 20 years to lie between the Frost & Sullivan projections and those of the MUSC report; hence the 7 to 14 percent per year range expected by the expert panel for therapeutic radiopharmaceutical market growth. The diagnostic radioisotopes market has also been analyzed by Frost & Sullivan and the expert panel; however, since Alternatives 1 and 4 would produce mostly therapeutic isotopes, only the therapeutic radiopharmaceutical growth is considered here.

The expert panel's predicted growth rates apply to a historical base value of $48 million in 1996 for the therapeutic radiopharmaceutical market (Frost & Sullivan 1997). However, it is generally accepted that the sales value of the isotope component is, on average, only about 20 percent of the sales value of a complete radiopharmaceutical product (Tenforde 2000). Hence, the therapeutic market in 1996 was actually about $10 million (not $48 million) in isotope sales volume in the United States. By applying the expert panel's projected growth rates of 7 to 14 percent per year to the $10 million 1996 base, the growth in the radioisotope component of the U.S. therapeutic radioisotope market can be calculated as shown in **Figure 3–1**. If growth rates of 7 and 14 percent were compounded annually, the value of that market could range from $50.7 to $232 million in the year 2020. None of the referenced growth rates have been extrapolated beyond a 20-year horizon. For purposes of this Cost Report, it was assumed that beyond the year 2020, a conservative 5 percent per year growth rate would apply to all projections. Extrapolation of the 7 and 14 percent growth curves beyond 2020 at a 5 percent growth rate to the year 2040 is also presented in Figure 3–1.

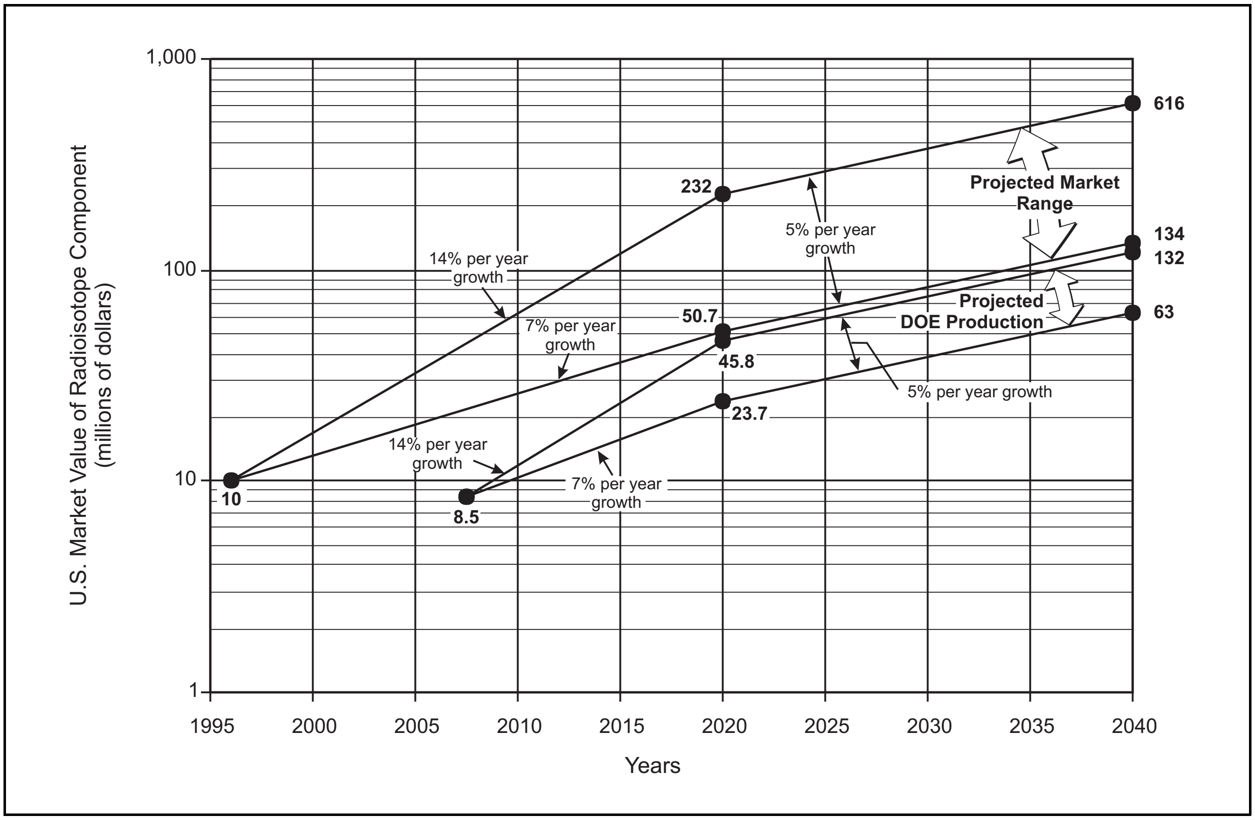

Figure 3–1 Therapeutic Radiopharmaceutical Market Forecasts

Projections of DOE Market Contribution—DOE's role as a supplier of isotopes for the commercial radiopharmaceutical market has been evaluated both by DOE and its advisory groups, e.g., the Nuclear Energy Research Advisory Committee (NERAC) and the expert panel (Wagner et al. 1999). Other suppliers include universities, commercial sources, and foreign suppliers. DOE is currently producing only about 10 percent of the reactor-produced isotopes needed by U.S. nuclear medicine (Frost & Sullivan 1997). At the same time, DOE also remains responsible for assuring a consistent supply of research and commercial isotopes that are not available in the marketplace. In addition, NERAC has recommended that DOE incorporate its policy of privatizing all commercially applicable technological developments derivable from its programs into its isotope production and development program. Current DOE plans, therefore, are to focus initially on the production of medical isotopes that exhibit the most significant medical potential, given an adequate supply, and to look to other promising areas of production when that potential is realized and sustained by supplies from private resources.

The extent to which FFTF, operating at 100 megawatts-thermal, could contribute to the supply of therapeutic radioisotopes has been estimated. One estimate puts revenues from FFTF sales at an average value of \$8.5 million per year between the years 2005 through 2010, and projects this to grow to revenues from \$23.7 to 45.8 million in the year 2020 (PNNL 1999). This growth (extended from 2020 through 2040 at an annual rate of 5 percent per year) also was plotted on Figure 3–1 for comparison with projections of the isotope growth. As indicated in Figure 3–1, in the year 2020, the higher estimate of medical isotope sales (\$45.8 million) accounts for about 20 percent of the projected growth (\$232 million). These isotope requirements are projected through the year 2040.

Integration of the areas under the two isotope supply curves in Figure 3–1 provides an estimate of expected revenues from therapeutic isotope sales. From the beginning of production through the year 2040, integration of the lower supply curve results in an estimate of about $1 billion in revenue, while integration of the higher supply curve indicates a total revenue of about $1.9 billion. This range of estimated revenues was developed for the therapeutic isotopes identified in the FFTF scoping document (PNNL 1999) and is, therefore, relevant to Alternative 1. The new research reactor (Alternative 4) would be designed to produce a similar (but not identical) set of therapeutic isotopes; thus, within the approximate nature of market forecasts, revenues of this magnitude could be realized in that alternative as well.

The employment of the low-energy cyclotron accelerator as the source of medical isotope production (Alternative 3) results in a somewhat different set of isotopes. Nuclear reactors produce radioisotopes by adding an extra neutron into the targeted atoms, resulting in an excess of neutrons, and making them radioactive. Low-energy cyclotron accelerators bombard atoms with different particles (protons), producing isotopes that are deficient in the number of neutrons; in this case, it is the neutron deficiency that makes the isotopes radioactive. This fundamental difference between the two processes generally means that reactor radioisotopes will not be made by a low-energy cyclotron accelerator, nor will low-energy cyclotron accelerator radioisotopes be made in a reactor, although there are some medical radioisotopes that can be made by both.

The medical radioisotopes that would be produced by nuclear reactors in Alternatives 1 and 4 are intended primarily for the therapeutic radiopharmaceutical market. Nevertheless, 14 accelerator-producible radioisotopes (7 of which are therapeutic) are included in the list of 28 radioisotopes recommended for DOE production by the expert panel convened by DOE to forecast future demand for medical isotopes (Wagner et al. 1999). Thus, it is probable that the cyclotron designed conceptually for Alternative 3 would produce medical radioisotopes for both the therapeutic and diagnostic markets. Although no market value has been cited for these radioisotopes, it should be noted that around the world there are about the same number of low-energy cyclotron accelerators as reactors producing medical isotopes as a major part of their functions (ANSTO 2000).

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APPENDIX A
BASIS FOR ESTIMATING THE COST OF CONSTRUCTING AND OPERATING ACCELERATOR(S) FOR THE PRODUCTION OF NUCLEAR ISOTOPES AND NUCLEAR RESEARCH AND DEVELOPMENT

Construction and operation costs were estimated for two types of accelerators designed for separate missions: (1) a high-energy proton accelerator that would generate neutrons for irradiating neptunium-237 targets for the production of plutonium-238, and (2) a low-energy cyclotron accelerator that would accelerate protons to low or medium energies to produce nuclear reactions on targets for the production of medical and industrial radioisotopes. Nuclear research and development could be performed in either accelerator. The costs of constructing and operating these accelerators were based on preconceptual designs, and were used in estimating the total cost of each of the three options in Alternative 3 presented in this Cost Report.

A.1 HIGH-ENERGY ACCELERATORS

High-energy accelerators can be designed to generate neutrons by bombarding a heavy metal target, such as uranium-238, or tungsten. During the bombardment, or "spallation" process, accelerated protons produce neutrons on uranium-238 targets. Uranium-238 produces about twice as many neutrons as tungsten because some are produced via fission as well as spallation. In the production of plutonium-238, the uranium spallation target would be surrounded by a blanket containing neptunium-237, water coolant, other neutron moderators, and structural materials. As in a nuclear reactor, the neptunium-237 would capture neutrons to produce plutonium-238.

A preconceptual high-energy linear accelerator (linac) designed for the production of 5 kilograms (11 pounds) of plutonium-238 per year (TechSource 2000) was evaluated in the NI PEIS. Construction and operation costs used in this Cost Report were based on this preconceptual design. These costs were scaled from estimates developed for another, much higher-energy linac system designed to produce 3 kilograms (6.6 pounds) of tritium per year (LANL 1997). Although no large-scale high-energy linac has ever been built for the purpose of converting high proton energies to neutron fluxes that can produce kilogram-quantities of radioisotopes, LANL has built and operated a low-energy demonstration accelerator (LEDA) that could eventually serve as the front-end section of its large tritium high-energy linac design. LEDA is capable of achieving proton energies of 7 million electron volts, of the total 1,300-million-electron-volt system design (Lynch et al. 1996).

Construction Costs—The estimated cost of constructing the high-energy linac and beam transport section of the system was developed by TechSource, Inc., using a cost/performance model similar to that used by LANL in its conceptual design for the tritium production high-energy linac (LANL 1997). Target/blanket costs, site and building costs, and balance-of-plant (power supply, heat removal, utilities and services, etc.) were also scaled from the LANL tritium high-energy linac system cost estimates. On the basis of this approach, and the application of contingencies resulting in an overall contingency factor of 26 percent, a final construction cost figure of $742.2 million was obtained by TechSource, Inc. The cost elements of this estimate are presented in **Table A–1.**

Table A–1 Construction Costs for a High-Energy Accelerator System Capable of Producing 5 Kilograms (11 Pounds) of Plutonium-238 per Year (Millions of FY 2000 Dollars)

Cost Element	*Cost*	*Cost with Contingency*
Accelerator	272.1	345.6 (544.2)
Target/blanket	37.5	52.5 (112.5)
Site and buildings	102.9	123.5
Balance-of-plant	68.3	82.0
Other project costs (design, permitting)	51.6	65.6
Subtotal	532.4	669.2 (927.8)
Project management	58.3	73.0
Total	590.7	742.2 (1,000.8)

Source: TechSource 2000.
Note: For Cost Report purposes, costs with adjusted contingency are shown in parentheses.

The contingencies used in the TechSource estimate are similar to those developed by LANL for the tritium high-energy linac in 1997, as are the overall system contingencies (28 percent of the LANL estimate; 26 percent in the TechSource estimate). A component-by-component analysis of technological risks was performed by LANL to support the cost estimate for the tritium high-energy linac (LANL 1997), and recent advances in the technical base for high-energy linac accelerators , together with the LEDA demonstration, have lent confidence in the view that these risks may be relatively low.

However, the contingencies proposed by TechSource may be considerably understated for two of the system components. The major area of cost uncertainty is in the performance of the high-energy accelerator target/ blanket system, in terms of efficiency of neutron production in the uranium spallation target, and efficiency in usage of neutrons in the conversion of neptunium-237 to plutonium-238 in the blanket. In addition, there are large uncertainties in the cost of the TechSource high-energy linac target/blanket systems, since they differ substantially from the system designed by LANL due to the use of uranium as the spallation target rather than tungsten, which is used in the LANL tritium high-energy linac design, and higher deposition density. Although both LANL and TechSource use a 40 percent contingency for target/blanket systems, a 300 percent contingency was assumed for those components in this Cost Report, and is shown in parentheses in Table A–1.

The second major area of uncertainty is the cost of the high-energy accelerator system itself. The tritium high-energy linac system conceptual design by LANL is considered to be at an intermediate level of technological maturity, and of moderate technical, cost, and schedule risk (LANL 1997). However, although the technology of electron acceleration is well demonstrated in high-energy linac accelerators, proton acceleration, to energies that can produce neutrons by spallation, is not. In particular, "beta cavities" (critical components which would be needed to bunch and accelerate a proton beam to an energy level suitable for the next accelerating structure) have yet to be demonstrated. Therefore, a 100 percent contingency was assumed for the plutonium-238-producing high-energy linac accelerator system in this Cost Report (as shown in parentheses in Table A–1), although LANL used a 28 percent contingency on their estimated cost of a tritium-producing high-energy linac, and TechSource used 26 percent on the estimated construction cost of their high-energy linac design for the production of plutonium-238.

Another area of uncertainty is the cost of developing and licensing a shipping cask for the high-energy accelerator target/blanket. As designed, the high-energy accelerator target/blanket assembly system consists of heavy-water-cooled layers of depleted uranium, surrounded by a 5-centimeter-thick (2-inch-thick), light-water-cooled neptunium-237 blanket. Slabs of beryllium 30 centimeters (1 foot) thick cover all but the beam-entrance face of the target/blanket assembly. In all, the weight of the dry target/blanket assembly is 588 kilograms (1,300 pounds), with a total heat load of 6,140 kilowatts. Although several options exist for handling the target/blanket assembly after the irradiation cycle, the entire target/blanket assembly would be removed from its surrounding beryllium reflector for cask shipment (TechSource 2000). A transport cask with an internal cavity 45 by 50 by 200 centimeters (18 by 20 by 79 inches) would be required to hold the irradiated assembly, and would weigh 35.5 metric tons (78,000 pounds). Since a usable shipping cask may not exist, a cost of $6 million has been estimated in the category of "other project costs" for the development, permitting, licensing, and procurement of this shipping cask. A minimum of six shipments per year would be required for the replacement of the target/blanket assembly during plutonium-238 production operations. The costs of fabricating and replacing target/blanket assemblies have been included in the operations and maintenance consumable operating costs in **Table A–2** (TechSource 2000).

Table A–2 Annual Operating Costs for a High-Energy Accelerator System Capable of Producing 5 Kilograms (11 Pounds) of Plutonium-238 per Year (Millions of FY 2000 Dollars)

Cost Element	*Cost*
Staffing (225 full-time employees)	21.1
Electric power, other utilities	7.5
Operations and maintenance consumables	12.0
Total operations and maintenance costs	40.6

Source: TechSource 2000.

The changes in the contingencies for the two system components discussed above, in addition to the procurement of the shipping cask, result in a total construction cost of $1 billion for the plutonium-238 high-energy accelerator system, as shown in Table A–1, and this cost was entered in the spreadsheets in Appendix E for Alternative 3.

The construction schedule, from inception of conceptual design and target/blanket prototyping to completion of startup, commissioning, and plutonium-238 production demonstration, runs for 7 full years. The construction spending profile can be distributed over the first 6 years, with startup and commissioning taking place during the final 18 months (TechSource 2000).

Operating Costs—The cost of electrical power would be expected to dominate, operating costs for a high-energy accelerator as in the case of the higher-energy tritium-producing linac system (LANL 1997), which has a 486-megawatt demand that accounts for 59 percent of the annual operations and maintenance cost for that facility. However, the lower-energy linac design for the production of 5 kilograms (11 pounds) of plutonium-238 per year (TechSource 2000) would require only 75 percent of the LANL tritium-producing line staff, while consuming just 36 megawatts of power. Thus, the lower-energy (TechSource 2000) design operations and maintenance cost would be dominated by the cost of its staff, as shown in Table A–2.

A.2 LOW-ENERGY CYCLOTRON ACCELERATORS

A preconceptual low-energy cyclotron accelerator was evaluated in the NI PEIS and would generate proton energies of up to 70 million electron volts, as compared to an output beam energy of 1,000 million electron volts for the high-energy linac accelerator (TechSource 2000). However, the protons accelerated by the low-energy cyclotron accelerator would have sufficient energy to interact directly with targets in nuclear reactions to produce medical and industrial isotopes. The low-energy cyclotron accelerator is a proven device for producing medical and industrial isotopes. Smaller low-energy accelerator machines are commercially available (although designed on a customer-by-customer basis) and are in commercial use producing medical radioisotopes.

The medical and industrial isotope production facility would consist of a new building to house the low-energy cyclotron accelerator, the proton beam lines, and the target room. Once the beam is extracted from the low-energy cyclotron accelerator, it is directed through focusing and steering magnets to the water-cooled production target. The targets would be installed and removed vertically from a hot cell, located on a floor directly above the target station. Supporting systems include power supplies for the magnets and accelerator; equipment for cooling, recirculating, and decontaminating water; a vacuum system; and a beam switchyard containing the switching magnets that direct the proton beam to the target. The costs of constructing and operating a new separate processing support facility, designed for the isolation, packaging, and shipment of the medical and industrial isotopes produced in the low-energy cyclotron accelerator, are discussed in Appendix C.

Construction Costs—A cost of $34.75 million, including a 20 percent contingency, was estimated for the low-energy cyclotron accelerator facility, over a three to four-year period of design and construction (TechSource 2000). This includes an estimated $13 million for the purchase of major items of vendor-supplied equipment, including the accelerator, beam lines, vacuum, and support equipment, which would be installed.

Operating Costs—A total annual operating cost of $4.5 million was conservatively estimated from cost component data (TechSource 2000), as follows:

- Staffing – an annual cost of $3 million was selected from the $2-to-3 million-per-year range cited (TechSource 2000).
- Operating costs, including power and utilities – an annual cost of $1 million was used, on the basis of a 144-hour week (“bounding operating cost”), rather than the 35-hour-week basis for the estimated operating cost of $0.243 million per year (TechSource 2000).
- Consumables – the annual cost of $0.05 million for “supplies” (TechSource 2000) was considered too low to cover the materials component of maintenance, targets, housekeeping, etc., and was increased by one magnitude to $0.5 million, for a total operating cost of $4.5 million per year.

A.3 References

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APPENDIX B
BASIS FOR ESTIMATING THE COST OF CONSTRUCTING AND OPERATING A RESEARCH REACTOR FOR THE PRODUCTION OF NUCLEAR ISOTOPES AND NUCLEAR RESEARCH AND DEVELOPMENT

Construction and operating costs were estimated for the research reactor designed for evaluation of Alternative 4 and described in Appendix E of the NI PEIS (DOE 2000a). These costs, based on a preconceptual design, are summarized in this appendix. To assure that the estimates are reasonable, these design-based costs were reviewed for sufficiency and compared to generalized historical research reactor costs. The results of this analysis also are presented in this appendix. This analysis determined that the design-based cost estimates correlate well with historical cost experience, when adjusted to current-year dollars. This correlation lends further credence to the validity of the preconceptual-design-based cost estimates.

B.1 RESEARCH REACTOR COST ESTIMATES

B.1.1 Construction Costs – Preconceptual Design Basis

The preconceptual design was presented in Appendix E of the NI PEIS (DOE 2000a) and includes basic elements of the research reactor facility sufficient for analysis purposes in the NI PEIS. However, it does not include design details (i.e., system and layout drawings, bill of materials, electrical and piping routing, etc.) commensurate with a complete preliminary reactor design. Although significant additional work would be required to develop a detailed preliminary design of the research reactor, the preconceptual design provides the basis for evaluating construction costs. To assure the reasonableness of these costs, they were compared with costs estimated on recent designs of research reactors in the United States, Canada, and Australia. Three steps were involved in making these comparisons: (1) a generalized description was determined for the cost of constructing a research reactor in terms of a key characteristic, such as power level; (2) cost estimates based on recent designs were correlated with this description to develop an equation as a predictive tool for the estimation of current research reactor construction costs; and (3) the reasonableness of the research reactor cost estimate was then tested by seeing whether it could be predicted by the equation.

To concurrently produce the required quantity of plutonium-238 along with medical and industrial radioisotopes, while accommodating nuclear research and development, it was determined that a reactor core power of 50 megawatts-thermal would be necessary. At this power level, the core would require an active cooling system with forced coolant flow to maintain the fuel below its thermal limits. The reactor cooling system would use a tank within a pool which is connected to primary coolant circulating pumps, a heat exchanger, and an ultimate heat sink consisting of two cooling towers. The pool would be housed in a reactor building which also would enclose the pumps, heat exchanger, secondary systems, and spent nuclear fuel storage pool. The spent nuclear fuel storage pool can be hydraulically connected to the reactor core pool for refueling and emergency flooding. The ultimate heat sink cooling towers, air exhaust stack, and emergency diesel generators would be located outside the reactor building (DOE 2000a).

The reactor core design consists of 68 fuel assemblies, each enclosing an 8-by-8 array of fuel rods based on an extension of a currently licensed low-enriched uranium Training Research and Isotope Production Reactor (TRIGA) fuel design (Simnad 1980). Some 800 rod positions in the fuel assemblies would be replaced by boron-carbide-clad control rods, a proven, accepted, and widely used neutron absorber. In addition, a number of plutonium-238 and medical and industrial radioisotope production target rods would occupy positions within the fuel assemblies. Nuclear research and production of radioisotopes that require short irradiation times can be accommodated by eight rabbit tubes located outside the fuel region of the core, but still within an area with a relatively high neutron flux (DOE 2000a).

The total project cost of the reactor, including the site, buildings, design engineering, installed cost of components and systems, and licensing and regulatory compliance costs, was estimated at $191 million (SAIC 2000). The addition of a 50 percent contingency, justifiable for a preconceptual design (Peters and Timmerhaus 1991), results in a total project cost of $287 million.

The breakdown of the project costs for a new research reactor (SAIC 2000) is presented in **Table B–1**.

Table B–1 Research Reactor Construction Costs – Preconceptual Design Basis

Cost Element	*Cost (millions)*	*Reference*
Beryllium core reflector	4	ABC 2000
Boron carbide control rod pellets	0.065	Kang 2000; Hailand 2000
Civil/structural/earthworks (concrete and steel)	7.5	Tripathi 2000a and 2000b
Major large-diameter (greater than 12 inches) piping	1	Tripathi 2000c
Two overhead cranes (nuclear safety grade)	1.5	Schaeffer 2000; Nordloef 2000
Two emergency power diesel generators (N-Stamp)	4	Lidbury 2000
Two primary coolant system heat exchangers (N-Stamp)	1.85	Holtz 2000
Two primary coolant system pumps (N-Stamp)	4.4	Dziekonski and Robertson 2000
Two primary coolant system pump motors	0.167	Kenton 2000
Two secondary coolant system pumps (commercial)	0.25	Dziekonski and Robertson 2000
Two secondary coolant system pump motors	0.167	Kenton 2000
Two cooling towers	3.1	Stacks 2000
Labor (160 workers for four years at $125,000 per year), including equipment rental	80	AECL 1996; ANSTO 1999
Conceptual design	5	Estimated
Title I design	10	Estimated
Title II design	15	Estimated
DOE license approval	10	Estimated
Construction management (including quality assurance)	20	Estimated
Other systems and components	23	Estimated
Subtotal	**191**	
50 percent contingency	96	
Total research reactor construction cost	**287**	

Source: SAIC 2000.

B.1.2 Operating Costs – Preconceptual Design Basis

Operating costs for a new 50-megawatt research reactor also were estimated as a part of the preconceptual design (SAIC 2000). These cost estimates, shown in **Table B–2**, exclude charges for the low-enriched uranium fuel itself, consistent with the cost assumption used in Alternative 1 that FFTF fuel would be “Government-furnished material.” Therefore, the fuel charge would be due solely to costs of fabrication.

Table B–2 Reactor Operating Costs – Preconceptual Design Basis

Cost Element	*Annual Cost (millions)*	*Reference*
Operating staff of 120 at $125,000 per staff member	15	IAEA 1998
Fuel, no-cost for low-enriched uranium	6.2	Razvi 2000
Electricity, 25 million kilowatt hours at $0.05 per kilowatt hour	1.25	DOE 2000b
Diesel fuel, 7,655 gallons at $1.50 per gallon	0.01	Lidbury 2000
Potable water, 210 million gallons at $4.06 per 1,000 gallons	0.85	WSSC 2000a
Sanitary sewage, 3,066,000 gallons at $5.18 per 1,000 gallons	0.02	WSSC 2000a and 2000b
Subtotal annual cost	**23.3**	
Total annual cost with contingency	**25**	

Source: SAIC 2000.

B.2 Generalized Cost Comparison Analysis for Research Reactor Construction and Operating Costs

B.2.1 Construction Costs Generalization

To assess the reasonableness of the estimated cost of constructing the research reactor based on its preconceptual design, a generalized cost relationship was developed. This step was followed by deriving a cost equation from the generalized relationship, which was then used as a predictive tool. If the equation confirms the estimated construction cost of the new research reactor, then that estimated cost may be deemed a "reasonable" cost.

Construction cost data were collected for 44 research reactors of all types, ranging from those dating back to the early postwar era to some that are currently under review or construction (IAEA 1998, INSC 2000, AECL/NRCC 2000, and PCA/PSCPW 1999). Historical costs of construction were escalated to year 2000 dollars by the ratio of the current (May 2000) *Engineering News Record* (ENR) Construction Index of 6223 (ENR 2000a) to the ENR index for the year of reactor construction. These cost and escalation data are shown in **Table B–3**.

The 44 data points were plotted on a log-log graph (**Figure B–1**), representing year 2000 construction costs (as the ordinate) versus the thermal power of the reactors in megawatts (as the abscissa). The rationale for this choice of data representation is a logarithmic relationship known as the "six-tenths power rule," commonly used in the chemical process industries for scaling equipment costs (Peters and Timmerhaus 1991). Mathematically, the rule can be shown as:

$$Cost\ of\ Equipment\ A = Cost\ of\ Equipment\ B \left(\frac{Capacity\ of\ Equipment\ A}{Capacity\ of\ Equipment\ B}\right)^{0.6} \qquad [1]$$

The logarithmic form of equation [1] has also been found to apply to the cost-per-size relationship for light-water-moderated nuclear power plants (EPRI 1979), with the exponent in the equation having a value of 0.47 rather than 0.6.

Table B–3 Research Reactor Construction Costs (Millions of Year 2000 Dollars)

Reactor (Country)	*Megawatts-Thermal*	*Cost in Millions of U.S. Dollars*	*Year [a]*	*ENR Construction Cost Index*	*Escalation Factor [b]*	*Cost in Millions of Year 2000 Dollars*
ASTRA (Austria)	10	2.4	1960	824	7.6	18
ATR (U.S.)	250	136	1967	1074	5.8	790
BNL–1 (U.S.)	30	20	1950	510	12.2	244
BR–1 (Belgium)	4	2.8	1956	692	9.0	26
BR–2 (Belgium)	100	28	1961	847	7.3	205
CABRI (France)	25	9	1963	901	6.9	60
CNF (Canada)	40	208	1998	5920	1.1	218
Democritos (Greece)	5	2.5	1961	847	7.3	18
DR–3 (Denmark)	10	4.9	1960	824	7.6	37
FRJ–2 (DIDO) (Germany)	23	12	1962	872	7.1	85
HBWR (Norway)	25	4	1959	797	7.8	31
HFBR (U.S.)	40	12	1965	971	6.4	77
HFIR (U.S.)	100	14.6	1965	971	6.4	94
HFR (Netherlands)	45	8	1961	847	7.3	60
HIFAR (Australia)	10	5	1958	759	8.2	43
HWRR–II (China)	15	7.2	1958	759	8.2	59
IEA–R1 (Brazil)	2	0.85	1957	724	8.6	7.3
JMTR (Japan)	50	20	1968	1155	5.4	108
JRR–2 (Japan)	10	2	1960	824	7.6	15
KUR (Japan)	5	0.7	1964	936	6.6	5
Lucas Heights (Australia)	20	166	1997	5825	1.1	177
McClellan [c] (U.S.-TRIGA)	1 △ = 1	16 △ = 3	1988 1996	4519 5620	1.4 1.1	22 3
MITR (U.S.)	5	3	1958	759	8.2	25
MNR (Canada)	5	2.1	1959	797	7.8	16
MTR (U.S.)	30	18	1952	569	1.1	197
MURR (U.S.-University of Missouri)	10	3.5	1966	1019	6.1	21
NBSR/NIST (U.S.)	20	12	1967	1074	5.8	70
NRU (Canada)	135	22	1957	724	8.6	190
NRX (Canada)	42	6.7	1947	413	15.1	101
PBF (U.S.)	40	17	1971	1581	73.9	67
Phebes (France)	40	17	1978	2776	2.2	38
Prague LWR–15 (Czech Republic)	10	3.7	1957	724	8.6	32
Prototype BWR (France)	120	28	1975	2212	2.8	79
RA–3 (Argentina)	2.8	10	1968	1155	5.4	54
RV–1 (Venezuela)	3	6	1960	824	7.6	45
SAFARI I (South Africa)	20	4.5	1965	971	6.4	29
SAPHIR (Switzerland)	10	1.8	1957	724	8.6	15
TR–2 (Turkey)	5	3	1981	3535	1.8	5
TRIGA MKII (Romania)	14	4	1979	3003	2.1	8
TRIGA MKII (Bangladesh)	3	6	1986	4295	1.4	8.7
TRIGA MKIII (Republic of Korea)	2	2.5	1972	1753	3.5	9
TRIGA MKII (Indonesia)	1	0.35	1964	936	6.6	2.3
TRR–1 (Thailand)	2	1.4	1962	872	7.1	10
TRR–2 (Taiwan)	20	100	1999	6060	1.0	103

a. Cost estimated for the year indicated. Year may not necessarily be the year of construction or initial operation.
b. Escalation factor is the ratio of the current (May 2000) ENR Construction Cost Index (6223) to the index shown in the previous column.
c. The symbol △ indicates the incremental costs of a 1–megawatt-thermal upgrade in capacity.

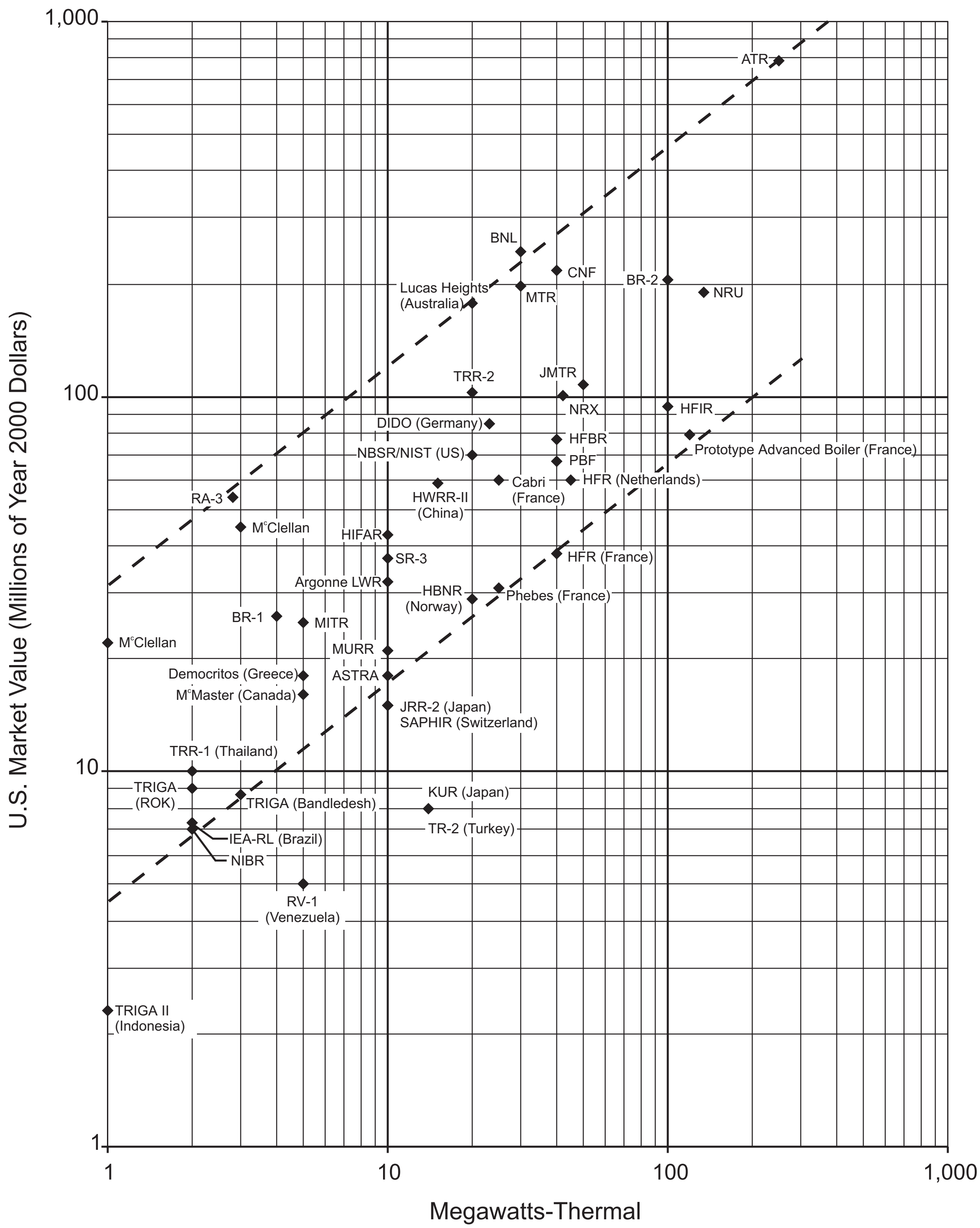

Figure B–1 Construction Cost as a Function of Thermal Power

Following the adaptation of the "six-tenths power rule" to nuclear power reactor costs (EPRI 1979), equation [2] indicates that the relationship for research reactors can be:

$$Cost\ of\ Reactor\ A = Cost\ of\ Reactor\ B \left(\frac{Megawatts\ Capacity\ of\ A}{Megawatts\ Capacity\ of\ B} \right)^{0.6} \qquad [2]$$

Although some expected scatter among the 44 data points is shown in Figure B–1, the two lines that bound the data are indicative of the logarithmic form of equation [1] and, indeed, have slopes of 0.6. Thus, the *form* of the research reactor cost generalization was established, and it remained to select a cost equation that could predict the cost of a new research reactor as a function of power. Most of the research reactors in the data sample were constructed prior to 1980, after which licensing requirements became increasingly stringent (see Table B–3). However, three reactors of recent design are of particular significance: the Advanced Neutron Source reactor (ORNL 1993), a 330-megawatt-thermal research reactor within a research center for neutrons, designed by ORNL; the Canadian Neutron Facility, a 40-megawatt-thermal reactor based on the multipurpose reactor technology of Atomic Energy of Canada, Limited (AECL/NRCC 2000); and the proposed 20-megawatt-thermal replacement for the High Flux Australian Reactor at Lucas Heights, New South Wales (PCA/PSCPW 1999). The costs estimated for the Canadian and Australian reactors are provided in Table B–3; however, as the estimated cost of the Advanced Neutron Source reactor was included within the $1.6 billion estimate for the entire research complex (ORNL 1993), an analysis of the work breakdown structure was undertaken to derive the cost of the reactor alone. The third level of the work breakdown structure (the most detailed level provided in the conceptual design report [ORNL 1993]) permitted the exclusion of some costs that would clearly be extraneous to the Advanced Neutron Source reactor itself. However, that level of detail provided no means for identifying additional equipment and support costs that should be excluded, prior to attempting with any degree of confidence to scale costs specific to the 330-megawatt reactor down to the 50-megawatt power level of the new research reactor. For this reason, the upper data-bounding line in Figure B-1 was drawn with a slope of 0.6 through the coordinates of the planned High Flux Australian Reactor at Lucas Heights, New South Wales. This line overestimates the cost of the Canadian Neutron Facility by a small margin, and can therefore be considered a reasonably valid representation of modern research reactor construction costs. As a function of thermal power, it can be expressed mathematically as:

$$\textit{Construction Cost (in millions of dollars)} = \log^{-1}[0.6 \log (\textit{thermal power, megawatts}) + 1.467] \qquad [3]$$

The test of the validity of the estimated $287 million cost estimated for constructing a new 50-megawatt-thermal research reactor (Table B–1) is whether it can be predicted by equation [3]. Solution of this equation for a 50-megawatt power level results in a figure of approximately $302 million. Thus, the test for the validity of the $287 million estimated cost is positive.

Although all historical reactor construction costs plotted in Table B–3 were escalated to year 2000 dollars, the costs near the upper bounding curve are far more credible because they are based upon estimates for reactors currently undergoing review, design, or construction. The reason for placing a lower level of confidence upon historical costs that have been escalated is that the ENR Construction Index is industry-wide, and probably understates the escalation of nuclear reactor construction costs. The greater-than-average escalation in the costs of research reactors, particularly isotope production reactors, may be due to: (1) broadening of the preconstruction design and review process to provide for compliance with updated safety criteria; (2) the long hiatus in research reactor construction, which would tend to increase the manufactured costs of specialized components and systems; and (3) the use of one-of-a-kind designs for the specific needs of isotope production reactors, as opposed to package or traditional research reactor designs.

B.2.1.1 Alternate Methods for Estimating Construction Costs

To test the reasonableness of the generalized cost relationship developed in Section B.2.1, two methodologies were used to predict the capital cost of the research reactor. The first method used the information from the Advanced Neutron Source (ANS) Conceptual Design Report (CDR) (ORNL 1993) as a benchmark to scale costs to obtain an estimate for the research reactor. The second method used an approach adopted from Plant Design and Economics for Chemical Engineers (Peters and Timmerhaus 1991), and makes a projection of the total capital investment based on the cost of equipment purchased for the CDR.

B.2.1.1.1 Method of Scaling Costs Specific to the ANS Reactor

The ANS was chosen as a benchmark because it is the most recently designed DOE research reactor. However, the ANS design is not an optimum benchmark from which to scale costs for this research reactor. ANS is a 330-megawatt reactor, primarily designed to support a wide-spectrum research mission. It contains design, equipment, and supporting elements that are not required for the scope of the 50-megawatt research reactor design, which is a minimalist design focused principally upon isotope production. To obtain an order-of-magnitude cost, the information from the ANS CDR was scaled using the information available at the third level of the project's work breakdown structure (WBS). This was the most detailed level reported in the CDR. A significant number of the nuclear research and development elements, all experimental system elements, and several elements associated with the construction of nuclear research and development support facilities were considered out of scope and eliminated. This initial scope reduction removed approximately $800 million of cost from the project. However, additional ANS equipment and support costs not necessary for the research reactor design still resided in the remaining third level WBS elements. A lack of detail in the CDR below the third level of the WBS prevented the elimination of these elements with their associated costs. Therefore, because of this additional content, any scaled costs from the ANS design would represent a conservative upper bound for the research reactor cost.

After the ANS scope elements were eliminated, scaling factors were required to scale costs from the remaining ANS elements to obtain the research reactor facility cost. The acreage-scaling factor was developed based on the assumption that the cost per acre for site preparation is constant. The ANS site is 67 acres and the research reactor site is projected to be 4 acres. A scaling factor of 4/67, or 0.06, was applied to the site preparation cost for the ANS to obtain a cost for the research reactor. The second scaling factor was developed to apply to the ANS operations elements that were essentially labor in support of construction. This operations-labor scaling factor of 0.38 was obtained from the ratio of key personnel required for the ANS (69 reactor operators) referenced to the number required for the research reactor (26 reactor operators). The third scaling factor, a facility-scaling factor, was derived from the “six-tenths power rule” for nuclear power reactor costs (Section B.2.1) and equals 0.32 (the ratio of the power level of the designed research reactor, to that of the ANS, taken to the six-tenths power, or [50/330] 0.6 = 0.32). This facility-scaling factor was applied to the remaining cost elements. Using the ANS as a benchmark, the sum of all scaled elements yielded an upper bound cost of $581 million for the research reactor. This approach yields a rough, order-of-magnitude agreement between the preconceptual research reactor design cost of $287 million and the scaled cost of $581 million derived from the ANS.

B.2.1.1.2 Method of Estimating Total Reactor Cost from Equipment Cost

Then another independent technique was used to obtain an additional reference mark for the research reactor cost. This second method used an approach adopted from Plant Design and Economics for Chemical Engineers (Peters and Timmerhaus 1991), and would yield another reference mark for the design cost of the research reactor. This approach estimates total project cost once the principal equipment has been specified.

It relates ancillary equipment and support as a multiplier of the principal equipment cost. A cost range for a conceptually designed new research reactor, presented in **Table B–4**, can be obtained from this approach:

Table B–4 Research Reactor Construction Costs—Equipment Multiplier Basis

No.	Capital Investment Cost	Method	Results (Millions of Dollars)		
			low	to	high
I	**Direct Costs**	**A+B+C+D**	**57.4**	**-**	**135.2**
A	Equipment and installation, etc.	1+2+3+4+5	42.3	-	85.4
1	Purchased equipment	given	28.0	-	28.0
2	Installation	25 to 55 percent of A1	7.0	-	15.4
3	Instrumentation and controls	6 to 30 percent of A1	1.7	-	8.4
4	Piping, installed	10 to 80 percent of A1	2.8	-	22.4
5	Electrical, installed	10 to 40 percent of A1	2.8	-	11.2
B	Buildings, process, and auxiliary	10 to 70 percent of A1	2.8	-	19.6
C	Service facilities and yard	40 to 100 percent of A1	11.2	-	28.0
D	Land	4 to 8 percent of A1	1.1	-	2.2
II	**Indirect Costs**	**A+B+C**	**9.2**	**-**	**101.4**
A	Engineering and supervision	5 to 30 percent of I	2.9	-	40.6
B	Construction and contractors	6 to 30 percent of I	3.4	-	40.6
C	Contingency[a]	5 to 15 percent of I	2.9	-	20.3
III	**Fixed Capital Investment**	**I+II**	**66.6**	**-**	**236.7**
IV	**Working Capital**	**10 to 20 percent of V**	**7.4**	**-**	**59.2**
V	**Total Capital Investment**	**III+IV**	**74.0**	**-**	**295.8**
Authorization basis		15 percent of V	11.1	-	44.4
Stakeholder outreach			0.5		
U.S. Nuclear Regulatory Commission licensing			2.0		
Startup		8 to 12 percent of III	5.9	-	35.5
Total Reactor Construction Cost			**93.5**	**-**	**378.2**

a. Contingency is 5 to 15 percent because error is built into each element.

Additional costs required for the facility to become operational under license within the DOE system were added to the estimated range of total capital investment. This analysis, while designed for large chemical plants, should be a reasonable way to establish a reference, rough, order-of-magnitude cost estimate for the research reactor, which requires similar components (i.e., pipes, pumps, control systems), design approaches, and construction techniques. For this exercise, the higher, more conservative estimate should be used as a reference point for the reactor construction cost. This projected value of $378 million, obtained by this method, is bounded by the results of both the ANS scaling method and the preconceptual design.

Although the cost estimate based on the preconceptual design ($287 million) is lower than both the scaled ANS cost ($581 million) and the method of estimating total costs from equipment costs (extreme value of $378 million), the $287 million figure was used in the computations for Alternative 4 because it is confirmed by the cost generalization for recent research reactor designs.

B.2.2 Operating Costs Generalization

Operating costs for 30 research reactors (IAEA 1998, INSC 2000, AECL/NRCC 2000, and PCA/PSCPW 1999) were tabulated in **Table B–5** and escalated to year 2000 annual costs. Reactor operating costs nominally include fuel costs as well as all direct costs for plant operations and maintenance, including labor, consumable supplies and equipment, insurance, and general and administrative costs (Sesonske 1973). Although no single index is sufficient to escalate all of these operating cost components, a 4 percent per year increase was applied to bring historical totals up to year 2000 dollar levels. This escalation factor represents an average for a 25-year trend in the ENR Building Cost Index (ENR 2000b), which reflects the costs of skilled labor and structural materials. In some instances (e.g., estimates of operating costs made in 1999 dollars), no escalation was made to the year 2000, as 4 percent was considered to be within the accuracy of the 1999 estimate. These cases are footnoted in Table B–5.

Table B–5 Research Reactor Operating Costs (Millions of Year 2000 Dollars)

Reactor (Country)	*Megawatts-Thermal*	*Operating Costs in Millions of U.S. Dollars per Year*	*Year [a]*	*Escalation Factor*	*Operating Costs in Millions of Year 2000 Dollars per Year*
ASTRA (Austria)	10	1.5	1993	(d)	2
ATR (U.S.)	250	–	–	(b)	45
BER–2 (Germany)	5	5.6	1993	(d)	7
BR–2 (Belgium)	100	18	1995	(d)	22
CNF (Canada)	40	–	–	(c)	14.2
DR–3 (Denmark)	10	2.4	1993	(d)	3.9
FFTF [b] (U.S.)	400	–	–	(b)	55
FRJ–2 (DIDO) (Germany)	23	11	1993	(d)	15
FRM (Germany)	4	1.6	1993	(d)	2.1
HFBR (U.S.)	60	–	–	(b)	24
HFIR (U.S.)	85	–	–	(b)	28
HFR (France)	57	20	1988	(d)	32
HFR (Netherlands)	45	17	1988	(d)	27
HIFAR (Australia)	10	5.3	1993	(d)	12
JMTR (Japan)	50	12	1988	(d)	19
JRR–2 (Japan)	10	5.2	1993	(d)	8
KUR (Japan)	5	0.7	1985	(d)	1.3
McMaster (Canada)	5	1.2	1986	(d)	1.9
MURR (U.S.-University of Missouri)	10	7	1991	(d)	10
NBSR/NIST (U.S.)	20	5.7	1993	(d)	7.5
NRU (Canada)	135	14	1993	(d)	18
NRX (Canada)	42	4	1993	(d)	5.3
PBF (U.S.)	40	7	1988	(d)	11
Phebes (France)	40	3.6	1988	(d)	5.8
Prague LWR–15 (Czech Republic)	10	1.2	1991	(d)	1.7
Prototype BWR (France)	120	5	1987	(d)	8.3
R–2 (Sweden)	50	8.8	1993	(d)	11.5
R–A (Yugoslavia)	6.5	1.0	1985	(d)	1.8
TRR–1/M1 (Thailand)	2	0.5	1962	(d)	2.2

a. Cost estimated for the year indicated. Year may not necessarily be the year of construction or initial operation.
b. No escalation applied to these costs (PNNL 1999).
c. No escalation applied to this cost estimated for a reactor under construction (Mirsky 2000).
d. Costs escalated from year of estimate to year 2000 by 4 percent per year.

These costs were plotted as a function of reactor thermal power and are shown in **Figure B–2**. As in the case of the capital costs, a logarithmic relationship is indicated by the straight lines, also with slopes of 0.6, that bound the data on this log-log plot. Thus, the operating cost analogy to the "six-tenths power rule" may be represented by equation [4]:

$$Operating\ Cost\ of\ Reactor\ A = Operating\ Cost\ of\ Reactor\ B \left(\frac{Megawatts\ of\ A}{Megawatts\ of\ B} \right)^{0.6} \quad [4]$$

The estimated annual operating cost of $25 million for the new research reactor, presented in Table B–2, falls just above the upper line in Figure B–2. This line represents the upper bound of the historical operating cost data. Thus, it may be considered a realistic cost, and has been used in the spreadsheets presented in Appendix E for Alternative 4.

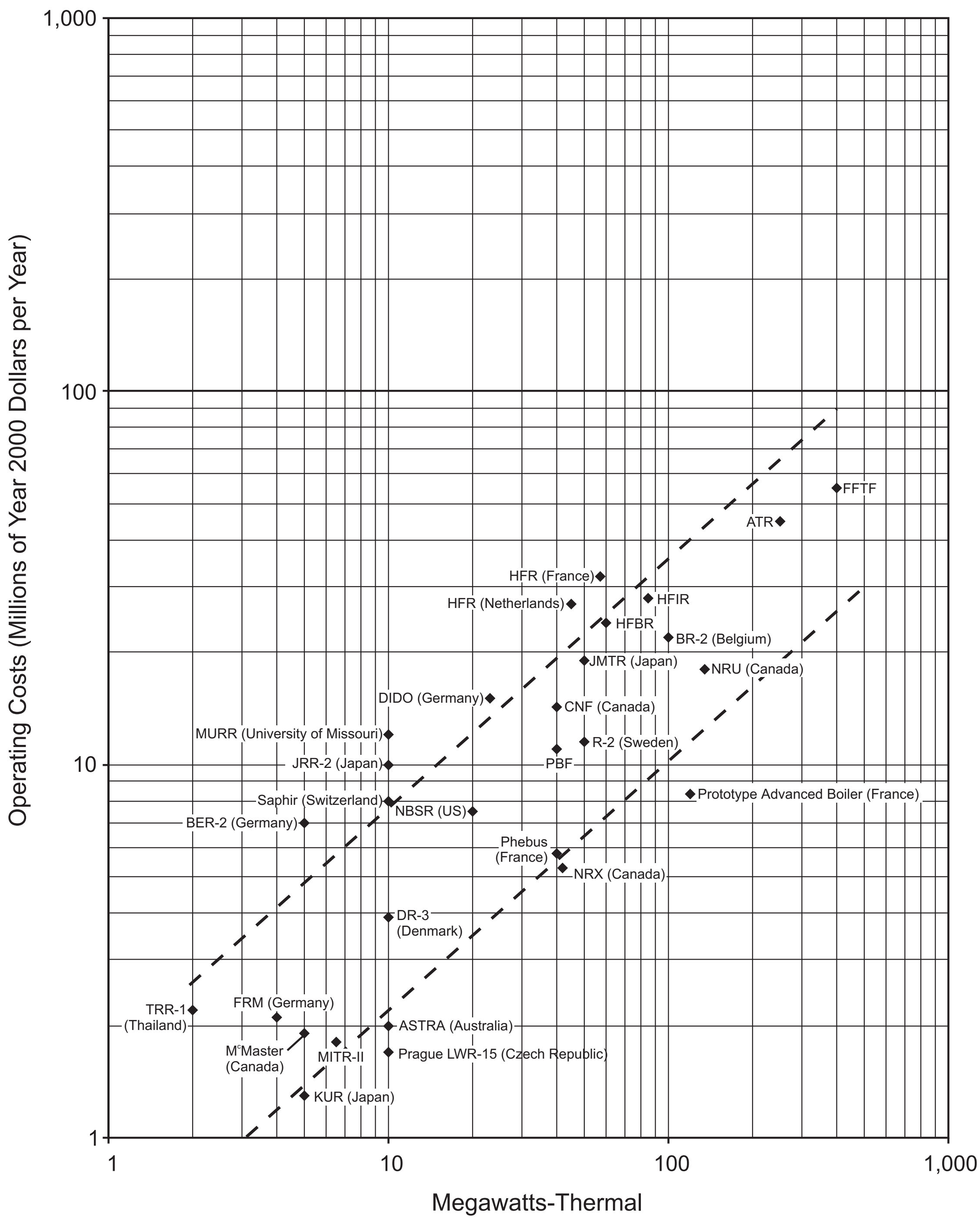

Figure B–2 Operating Costs as a Function of Thermal Power

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APPENDIX C
BASIS FOR ESTIMATING THE COST OF CONSTRUCTING AND OPERATING A NEW PROCESSING SUPPORT FACILITY FOR THE PRODUCTION OF MEDICAL AND INDUSTRIAL ISOTOPES AND NUCLEAR RESEARCH AND DEVELOPMENT

The cost of constructing and operating a new processing support facility was based on a preconceptual design. The facility was designed to support the medical and industrial isotope production and nuclear research and development missions by fabricating targets for irradiation at either a new accelerator (Alternative 3) or a new research reactor (Alternative 4). The facility would also receive return shipments of irradiated targets and process them to isolate medical radioisotopes for packaging and ship them to commercial pharmaceutical distributors.

The new processing support facility would have hot cells and laboratories to house the equipment necessary to set up target fabrication lines, receive and reprocess irradiated targets, and package and ship product radioisotopes. In addition to the medical isotope production mission, the new processing support facility would support the DOE nuclear research and development mission in the areas of target fabrication, investigation of the properties of irradiated targets, separation methods, materials testing, radiation resistance testing, and nuclear fuels research.

To accommodate these missions, the new processing support facility would be located at a generic DOE site in the general vicinity of the new irradiation facility (low-energy accelerator or research reactor). The new processing support facility would be a one-story above-grade building of about 15,850 square meters (52,000 square feet) in area (including a basement of 4,877 square meters [16,000 square feet], housing utilities and liquid retention tanks), designed around a center area containing the highest-risk activities. Irradiated materials would enter a loading dock with a straight-line access to the primary facility hot cell and access to a conveyor that could remotely transport samples to the hot process laboratories. In addition, samples from the hot cell could be transferred to hot nuclear research and development laboratory gloveboxes for analysis and testing. Other provisions would include cold target fabrication areas, offices, conference rooms, and building utilities.

C.1 FACILITY CONSTRUCTION

The cost elements used to determine the total estimated construction cost of $59.1 million (in FY 2000 dollars) are presented in **Table C–1**.

Table C–1 New Processing Support Facility Construction Costs (Millions of FY 2000 Dollars)

Item	*Cost (Plus 20 Percent Contingency)*
15,850-square-meter (52,000-square-foot) building shell	21
Design	
Title I and II	5.5
Title III	2.1
Construction management	5.5
Equipment	25
Total	59.1

Source: SAIC 2000.

Reasonableness of Construction Cost Estimate

There is no recent comparable design for a stand-alone radiological isotope processing facility that might provide some basis for evaluating the reasonableness of the new processing support facility construction estimate of $59.1 million.

An order-of magnitude estimate might be obtained by expressing a historical cost in terms of current dollars. For example, DOE's $8 million cost in constructing each of the two REDC buildings at ORNL in 1966 (Wham 2000) is approximately equivalent to $40 to 50 million in year 2000 dollars. The addition of laboratory equipment could easily double this figure to $80 to 100 million. The new processing support facility and REDC have approximately the same building floor area.

Another approach could be to compare the estimated cost of the new processing support facility with the estimated cost of replacing an existing facility. In the example chosen, the replacement cost of the high-activity 222-S analytical laboratory at Hanford has been quoted as $300 million (Sutter and Hogroian 1996). However, the two laboratories are quite different in size, as the 222-S facility includes 11 hot cells and 31 laboratories, compared to the new processing support facility's single hot cell and 10 laboratories. It would therefore appear that the new processing support facility should cost no more than one-fourth to one-third as much as a replacement 222-S, or $75 to 100 million.

The estimated $59.1 million cost of the new processing support facility is about 25 to 65 percent less than costs derived on the basis of these approximations, and it is therefore within the realm of reason.

C.2 ANNUAL OPERATING COSTS

New processing support facility staffing would constitute a major component of the annual operating costs of a new processing support facility. The number of full-time employees that would be engaged in facility operations are listed in **Table C–2**.

Table C–2 Number of New Processing Support Facility Full-Time Employees, By Function

Function	*Full-Time Employees Required*
Target fabrication and testing	20
Target handling	6
Radiochemical processing	21
Product packaging and shipping	7.5
Waste management	4
Nuclear research and development support mission	12
Facility support (janitorial, safety, shops)	24
Customer service (marketing, administrative)	5.5
Total	100

Source: SAIC 2000.

An average wage rate of $65 per hour was applied to the total of 100 full-time employees, for an annual staffing cost of $13.5 million. This figure, and other components of the $23.25 million annual operating cost of the new processing support facility, is presented in **Table C–3**. Startup and testing costs of $12 million would be incurred in the first year of operation after construction completion.

Table C–3 New Processing Support Facility Annual Operating Costs in Millions of FY 2000 Dollars

Cost Component	***Annual Cost (Plus 20 Percent Contingency)***
Staffing	13.5
Laboratory analyses	0.56
Waste handling	0.16
Target isotope materials	5.43
Miscellaneous (supplies, utilities, etc.)	3.6
Total	23.25

Source: SAIC 2000.

Reasonableness of Operating Cost Estimate

The estimated annual operating cost of $23.25 million for a stand-alone new processing support facility should be comparable to the operating cost for RPL/Building 325 at Hanford, which has a similar mission, but only reported an operating cost of $12.1 million (Nielsen 2000). The difference is believed to be due largely to the inclusion of support personnel (janitorial, machinists, radcon, safety) in the new processing support facility estimate (SAIC 2000), shown to be 24 full-time equivalents in Table C–2, and personnel devoted to the nuclear research and development mission, or 12 full-time equivalents, for a total of 36 full-time equivalents in support of, but not directly involved in, the medical and industrial isotope production mission. This would increase the 75 full-time equivalents in Building 325 (PNNL 1997) to 111, and increase the operating cost by about $6.4 million, bringing it up to about $18.5 million annually, or more in line with the operating cost of a new processing support facility, which is therefore considered reasonable.

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APPENDIX D
BASIS FOR ESTIMATING TRANSPORTATION COSTS

DOE policy requires compliance with applicable Federal regulations regarding domestic shipments of neptunium-237 and plutonium-238 materials. The overland transportation costs cover two types of truck transporting vehicles. Special vehicles and trailers (safe secure trailers/safeguards transporters [SSTs/SGTs]) are used for materials that require safe secure shipments. It was assumed that unirradiated neptunium-237 targets, including all target assemblies earmarked for irradiation in the new high-energy accelerator, new research reactor, and FFTF, would require shipment by SST due to the amount of neptunium-237 incorporated within the targets. Also, SSTs would be used for all shipments of plutonium-238. Transportation costs include costs for security (Clark 2000). All shipments of medical and industrial isotope targets and products can be shipped by commercial carriers.

D.1 TRANSPORTATION COSTS

As noted in Section 1.4, Cost Methodology, transportation cost estimates (Clark 2000) were based upon actual operational costs for escorted (security) shipments. The Transportation Safeguards Division of DOE's Albuquerque Operations Office developed these two-way costs based on data supplied on sites, facilities, and road distances involved in intersite shipments for each option (DOE 2000). Since the Transportation Safeguards Division operating procedures are classified, the operational details relevant to the development of the cost estimates cannot be published. The number of shipments that would be required for each alternative was obtained from the NI PEIS (DOE 2000) and is explained in Section 1.5, Assumptions and Schedules.

Transportation costs between facilities involved in the production of medical and industrial isotopes include: (1) intrasite transportation of isotope targets to irradiation facilities; (2) intrasite transportation of irradiated targets to processing facilities; and (3) offsite transportation of separated and packaged isotopes to air freight facilities. **Table D–1** presents transportation assumptions, including mode of transport, number of shipments, and source of transportation cost data for alternatives analyzed in the NI PEIS.

Transportation costs between facilities involved in the production of plutonium-238 include: (1) 33 shipments of neptunium-237 from SRS to storage or target fabrication and processing facilities; (2) shipments of neptunium-237 targets to irradiation facilities; (3) return shipments of irradiated neptunium-237 targets for the recovery of the plutonium-238; and (4) shipments of the plutonium-238 product to LANL. Transportation costs include costs for security (Clark 2000). Transportation cost estimates vary depending upon the carrier (commercial truck or SST), number of vehicles required, and shipping container.

Table D–2 presents an overall summary of inland routes (points of origin and destination) and associated distances in kilometers/miles. These distances were used to estimate the transportation costs for shipping neptunium-237 and plutonium-238 materials in safe secure trailers. Costs per mile were provided by the Transportation Safeguards Division of DOE's Albuquerque Operations Office.

A commercial truck transportation quote of $2.55 per mile was provided by A. J. Metzler Hauling and Rigging, Inc. (Eblen 2000). Subsequent conversations with Mr. Stephan Schmid, Operations Specialist, Science Applications International Corporation, Oak Ridge, Tennessee; and Mr. Don McCarty, United States Enrichment Corporation's Transportation Manager, Portsmouth, Ohio, determined by consensus that $3.00 per mile would be the best estimate, due to the possibility of unforeseen commodity weight or dimension changes.

Table D–1 Transportation Assumptions: Mode of Transport and Number of Shipments

Material	*Mode of Transportation*	*Source of Cost Data*
Neptunium-237 from SRS to storage and/or target fabrication and processing facilities	3 SST/SGTs per shipment	DOE Transportation Safeguards Division (Clark 2000)
Russian plutonium-238	2 SST/SGTs per shipment	DOE Transportation Safeguards Division (Clark 2000)
Unirradiated neptunium-237 targets to irradiation facilities	1 SST/SGT (Alternatives 1, 3, and 4) and commercial truck (Alternative 2, except for the options using the CLWR) per shipment	DOE Transportation Safeguards Division (Clark 2000); A. J. Metzler Hauling and Rigging, Inc. (Eblen 2000)
Irradiated neptunium-237 targets to plutonium-238 processing facilities	Commercial truck (Alternatives 1, 2, and 4) and 1 SST/SGT (Alternative 3) per shipment	A. J. Metzler Hauling and Rigging, Inc. (Eblen 2000); DOE Transportation Safeguards Division (Clark 2000)
Plutonium-238 to LANL	2 SST/SGTs per shipment	DOE Transportation Safeguards Division (Clark 2000)
Medical and industrial isotopes	Commercial truck	A. J. Metzler Hauling and Rigging, Inc. (Eblen 2000)
MOX and HEU fuel to FFTF	8 SST/SGTs per shipment of MOX and 4 SST/SGTs per shipment of HEU	DOE Transportation Safeguards Division (Clark 2000)

Table D–2 Summary of Transportation Routes and Mileage for Estimating the Cost of Safe Secure Trailer/Safeguards Transporters and Commercial Truck Transport

Routes			
Origin	*Destination*	*Distance in Kilometers*	*Distance in Miles*
Port of entry	LANL	3,250	2,018
Port of entry	FFTF	4,677	2,904
B&W Lynchburg	FFTF	4,516	2,804
SRS	REDC	604	375
SRS	CPP-651/FDPF	3,729	2,316
SRS	FMEF	4,429	2,750
REDC	FFTF	4,020	2,496
REDC	ATR	3,320	2,062
REDC	HFIR	Intrasite	Intrasite
REDC	CLWR	4,000	2,484
REDC	Accelerator or research reactor	4,000	2,484
REDC	LANL	2,383	1,480
FDPF	FFTF	1,007	626
FDPF	ATR	Intrasite	Intrasite
FDPF	HFIR	3,320	2,062
FDPF	CLWR	4,700	2,919
FDPF	Accelerator or research reactor	4,000	2,484
FDPF	LANL	1,846	1,146
FMEF	FFTF	Intrasite	Intrasite
FMEF	ATR	1,007	626
FMEF	HFIR	4,020	2,496
FMEF	CLWR	5,400	3,353
FMEF	Accelerator or research reactor	4,500	2,795
FMEF	LANL	2,546	1,581

Source: NI PEIS Appendix J (DOE 2000).

D.2 SHIPPING AND HANDLING OF NEPTUNIUM-237 TARGET ASSEMBLIES

It has been suggested that the GE-2000 shipping cask (GE Nuclear Energy 1996) be used to transport both unirradiated and irradiated neptunium-237 targets between target fabrication/chemical processing sites and accelerator or reactor sites in plutonium-238 production operations (Wham 1999). One such cask, in continual use, would be sufficient to fulfill the plutonium-238 production mission.

The cost of loading, receiving, and unloading was included in the overall transportation costs for each option. This cost was estimated to be $7,700 (Scullion 1995), or about $8,500 in FY 2000 dollars.

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